

AERO SPACE

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MAY 2024

**CONNECTING SPACE
TO AIR POWER**

ATTRITABLE DRONES

**FIGHTER PROJECTS
AROUND THE GLOBE**



DOMINATING THE SKIES

FUTURE COMBAT AIR SYSTEMS TAKE SHAPE



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Tempest

Securing control of the air
from 2035 and beyond



EDITORIAL

Defending the skies

One year ago, at the 2023 RAeS Future Combat Air Summit, the world was still reeling from the Russian invasion of Ukraine 15 months earlier – which saw peer-on-peer war break out in Europe and highlighted the importance of the lost art of control of the air.

This year, as *AEROSPACE* goes to press ahead of the 2024 RAeS Future Combat Air and Space Capabilities Summit, another conflict is again demonstrating why nations around the world are investing in flexible air power and developing next-generation fighters and drones. The mass strike by Iran on Israel on 13 April, saw over 300 drones, cruise missiles and ballistic missiles used – with 99% being successfully intercepted by airborne and ground defences, according to the IDF. Crucially some of these were downed by fighters not just from Israel, but from the US, Jordan and the UK – a product of decades of joint training and co-operation. Sharing of information in intercepting this complex and massive raid, deconflicting with multiple partners, to allow air and ground forces to take down this armada is key and something that will only increase in importance in the future combat platforms now on digital drawing boards.

In this special themed issue we explore the future of air power technology from attritable drones to digital design, connecting the space to the air cloud, cognitive EW/AI and the international fighter programmes and industrial partnerships that aim to leverage these breakthroughs and incorporate them into air platforms – as we stand on the cusp of a revolution in combat air.

This month's Future Combat Air and Space Capabilities Summit on 21-23 May, with speakers ranging from industry, academia and air arms, is set to be once again a must-attend event that will provide a unique insight into this revolution. I hope you will join us there.

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Front cover - rendering of GCAP over London. (Leonardo)



Additional content is available to view online at: aerosociety.com/aerospaceinsight
Including: 'Looking Back... to the Future' at the BBGA Conference, Avoiding orbital mayhem, UK aims for the stars – Space-Comm Expo 2024, Pilot mental health – can AI-powered psychological assessment help, Atlas goes from strength to strength – A400M celebrates 10 years in service

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Blueprint

Aurora capsule

Width	16ft
Weight	3.9t
Passengers	8 (+ 1 pilot)
Internal volume	30.4sq ft
Speed	12mph
Cruising altitude	25-35km

Augmented reality

The Aurora will come with large 360° panoramic windows surrounding the passenger seats, with integrated augmented reality (AR) to spot landmarks, flight information and bring up stargazing charts.

SPACEFLIGHT

Getting the overview effect

Spanish 'near-space' balloon tourism company, HALO Space has revealed the design of its 'Aurora' passenger capsule, created by renowned US industrial and automotive designer, Frank Stephenson. The company, which has already flown five test flights and plans a sixth in June, aims to offer luxury stratospheric 'near-space' experiences for passengers from 2026. The pressurised capsule, seating eight plus a pilot, will slowly ascend to an altitude above 25km beneath a helium balloon, with passengers able to experience sunrise and the curvature of the Earth for two to four hours. Descent will be by a steerable parafoil flown by the pilot that is deployed at a height of 6km. The whole flight will last six hours. Prices for a flight, which include a luxury 'glamping' experience, would start at \$164,000 with the company aiming to fly 10,000 passengers to 'near-space' by 2030 from launch sites in Australia, Spain, Saudi Arabia and the US.

A wide-angle view from inside the Aurora capsule looking out through a large, curved window. The Earth's horizon is visible, showing a thin blue line of the atmosphere above a vast expanse of white clouds and blue oceans. The interior of the capsule is dark, with parts of the window frame and a metallic latch visible in the foreground.

Triple safety

As well as the landing/recovery square parafoil, the Aurora capsule also includes two emergency in-line round parachutes that would be triggered in the event of a total failure of the helium envelope.

Point-to-point travel

While initial flights would launch and recover from the same place, CEO Carlos Mira suggested that point-to-point stratospheric balloon luxury travel could also be possible in the future, with the endurance of the balloon limited by the capsule's oxygen supply.

Are you sitting comfortably?

Seats have been carefully designed, not only from an aesthetic point of view, according to Stephenson, but also with safety and energy absorbing qualities. On take-off and landing, the seats will swivel to face into or away from the direction of travel, as per FAA regulations. Meanwhile, storage for a meal and refreshments of choice will also be built into the seat.

Radome

AIR TRANSPORT

FAA advised to remove pilot mental health stigma

The Mental Health and Aviation Medical Clearances Rulemaking Committee, created by the FAA to investigate pilot mental health, has published a 69-page report recommending that pilots be allowed to get 'talking therapy' without having to disclose it in their flight medical. It is the first of an eventual 24 recommendations,

aimed at eliminating the fear pilots have of losing their jobs by reporting medical problems. The committee noted that the FAA currently assumes that those who seek help with mental health may not be safe to fly. (See 'Pilot mental health – can AI-powered psychological assessment help?' *AEROSPACE* Insight blog, 5 April 2024).

AEROSPACE

Boom XB-1 flies



Boom Supersonic flew its XB-1 prototype aircraft for the first time on 22 March. The 12-minute flight from the Mojave Air & Space Port saw the so-called 'Baby Boom' reach 7,120ft and 238kts. The vehicle is a proof-of-concept aircraft, designed to test elements of the company's planned Overture supersonic airliner.

UKRAINE CONFLICT

DEFENCE

Ukraine repurposes GA aircraft as long-range kamikaze drone

On 2 April, Ukrainian forces conducted their deepest drone attacks of the war, targeting multiple sites more than 680 miles from the Russian border. Among the reported targets was an alleged Russian



Shahed-136 factory complex in Tatarstan, with the aircraft hit by what appeared to be a converted Aeroprakt A-22 Foxbat ultralight aircraft. In another blow for Russian forces, one of its Tu-22M3 bombers was shot down over Russia's Stavropol Krai, 300km from the front line on 19 April with Ukrainian sources saying that the aircraft had been downed by a long-range SAM, using similar methods employed to shoot down two A-50 AEW aircraft earlier this year. Two of the four crew ejected, with one dead and another missing.

SPACEFLIGHT

Australia closer to first orbital space launch

Australia's first orbital rocket, built by Gilmour Space Technologies, is inching closer to its inaugural launch, dubbed ErisTestFlight1. The 23-metre-tall Eris rocket has been lifted onto the launch pad at the Bowen Orbital Spaceport in Queensland ahead of its planned lift-off on 4 May 2024, hinging on an approval from the Australian Space Agency. The three-stage rocket will

be capable of delivering up to 305kg to LEO and the firm hopes to complete its second flight in 2025. Gilmour Space itself received a boost in funding in February after raising a \$55m Series D round, led by Queensland Investment Corporation (QIC), Blackbird, Main Sequence. The site in Queensland was the first to ever receive approval for an orbital launch licence in early March this year.

NEWS IN BRIEF

Chinese AAM developer, Autoflight's V2000CG CarryAll cargo drone received Chinese CAAC type certification on 22 March, becoming the first lift + cruise configuration eVTOL in the world to be certificated. Certified in the large UAV class (empty weight greater than 116kg and MTOW greater than 150kg), the ceremony also saw Chinese delivery company, ZTO order 30 CarryAlls.

Korean Air has become the latest customer for the Airbus A350 family after finalising an order for 33 aircraft placed on 2 April. The order covers 27 A350-1000s and six A350-900s.

After approval from the US, Argentina has signed an agreement with Denmark to acquire 24 of its surplus F-16s fighters – restoring a supersonic fighter

capability that was lost when its Mirages retired. The \$320m acquisition includes AIM-9X and AIM-120 missiles, four flight simulators and spare engines.

NASA has downselected three private teams to design lunar rovers for its Artemis Moon missions. The commercial teams, led by Intuitive Machines, Lunar Outpost and Venturi Astrolab, will work on a Lunar Terrain Vehicle

(LTV) with the goal of the chosen design being driven on the Moon in 2030 with the Artemis V mission.

Icon Aircraft, the California-based company that manufactures the ICON A5 amphibious aircraft, has filed for US Chapter 11 Bankruptcy. The company filed for voluntary relief with the United States Bankruptcy Court for the District of Delaware, with affiliated debtors, Ryon,

IC Technologies and Icon Flying Club. During the restructuring process, Icon will continue to produce and market its aircraft.

US hypersonic start-up, Hermeus has unveiled its first flyable aircraft. The uncrewed Quarterhorse Mk1 is powered by a GE J85 engine and, while it will not be hypersonic, it is hoped the airframe will provide valuable flight test data on remote take-off and landing when it takes

AIR TRANSPORT

Wizz Air to be launch customer for UK 'sewage to SAF' initiative



European low-cost carrier, Wizz Air is to be the launch customer for a new form of SAF made from sewage 'biosolids' with an order for 525,000t. The process, developed by UK-based Firefly, takes treated human waste from water companies, and converts it into SAF using hydrothermal liquefaction. Firefly CEO, James Hygate briefing media in London said that sewage could be the "cheapest and most abundant" feedstock for SAF. Firefly is now building a refinery in Harwich, UK with the goal of supplying airlines from 2028.

GENERAL AVIATION

UK GA accident rate stubborn, despite reduction in flying hours

The annual UK Air Accidents Investigation Branch (AAIB) safety review of incidents occurring in 2023 reveals that the agency received 790 occurrence notifications (compared to 778 in 2022). There were ten investigations into fatal accidents which involved 11 deaths. All involved GA aircraft which consisted of seven light aircraft, two gliders and a single hot air balloon. The gliders

were involved in a mid-air collision, the first for nine years. Commenting on the accidents, AAIB Chief Inspector, Crispin Orr noted: "Loss of control in flight continues to be the prevalent cause of fatal accidents." However, the latest figures come despite a reduction in GA flying hours in the UK by 50% since 2000 with private flying not yet recovered to pre-Covid levels.

to the skies from Edwards AFB later this year. The follow-on Mk2 equipped with a P&W F100 engine, will test high-Mach autonomous flight.

Following the blow-out of an Alaska Airlines' Boeing 737 MAX door plug on 5 January, the US Federal Bureau of Investigation (FBI) has contacted passengers on the flight to notify them they might be victims of a crime. In a letter to passengers, the agency

said: "This case is currently under investigation by the FBI." The US DoJ is already conducting an investigation into Boeing.

Greece is to acquire 35 Lockheed Martin/Sikorsky UH-60M Black Hawk helicopters in an announcement made on 5 April. The deal is worth €1.15bn.

Boeing's delayed Starliner capsule has been hoisted atop a ULA

AEROSPACE

Rolls-Royce tests Pearl 10X



Rolls-Royce's latest Pearl engine, the 10X, has begun its flight-testing campaign in Tucson, Arizona. The Pearl 10X is the latest engine designed for the business aviation market and be tested on the company's Boeing 747 test bed. Dassault Aviation selected the Pearl 10X for its new Falcon 10X jet, set to enter service in 2025, marking the first time the French manufacturer will use a Rolls-Royce engine to power its bizjets.

DEFENCE

Israel and allies repulse mass Iranian drone and missile strike

On the night of 13/14 April, Iran and its proxy forces in Iraq and Yemen launched a mass air attack of over 300 Shahed-136 one-way attack drones, cruise and ballistic missiles, with the vast majority being shot down by Israeli, Jordanian, US and UK fighter jets, as well as ground and sea-based air defences. Intelligence of a possible Iranian strike

beforehand enabled Israel to put its forces on high alert and friendly nations to deploy extra assets. The attack caused widespread disruption of civil air traffic in the region with Israel, Jordan, Iraq and Lebanon closing their airspace temporarily over the weekend, aircraft rerouting, and some airlines cancelling flights. (See News Analysis, p 11).

agreement to have the vehicle produced under licence in China. The deal with Hebei Jianxin Flying Car Technology Co grants it exclusive rights to manufacture and distribute the AirCar in the region.

Cranfield University is set to spearhead the research and development of the first major hydrogen technology hub to demonstrate the potential of hydrogen

as a net zero aviation fuel. The investment in the Cranfield Hydrogen Integration Incubator (CH2i) comprises £23m from Research England's Research Partnership Investment Fund (UKRPIF) and a further £46m committed from industry partners and academic institutions. CH2i will create a full ecosystem at Cranfield, connecting the production and use of hydrogen for aviation.

Radome

AIR TRANSPORT

Spirit to furlough pilots, delay deliveries

Due to ongoing turmoil at loss-making Spirit Airlines, after being affected by Pratt & Whitney GTF engine issues and the rejected \$38bn merger with JetBlue, the US low-cost airline will now delay the delivery of several Airbus A320neo jets that were set to arrive between 2025 and 2026. According to an announcement on 8 April, the aircraft are now scheduled to arrive from 2030 to

2031. This move is hoped will improve the company's liquidity by \$340m over the next two years. The company also announced that, as a result, it intends to furlough approximately 260 pilots from 1 September 2024. While the company secured compensation from P&W for GTF engine issues, a change in accounting methods meant it was heading for a larger Q1 loss than expected.

DEFENCE

First Kazakh A400M breaks cover



Airbus Defence has shared photos of the first of two A400Ms for Kazakhstan fresh out of the paint shop. Ordered in 2021, the Kazakhstan AF A400M features an unusual gloss grey paint scheme and Soviet style red 'Bort' numbers.

SPACEFLIGHT

Delta bows out after 60 years

United Launch Alliance (ULA) blasted off its Delta IV Heavy rocket for the final time on 9 April, marking the end of the 60-year Delta programme. The rocket launched from Space Launch Complex-37 at Cape Canaveral Space Force Station in Florida at 12:53pm EDT, carrying the NROL-70 mission for the National Reconnaissance Office (NRO). The final Delta IV Heavy version first flew in December 2004 and completed 16 launches during its lifespan, 12 of which were for the NRO.



AEROSPACE

Calhoun to step down at Boeing by end of the year

Boeing President and CEO, Dave Calhoun announced on 25 March that he has decided to step down as CEO by the end of 2024. In a statement, he said he would continue to lead Boeing through the year to complete the critical work under way to stabilise and position the company for the future. Meanwhile, Board Chair, Larry Kellner has

informed the board that he does not intend to stand for re-election and the board has elected Steve Mollenkopf to succeed him with the goal of recruiting a new CEO. In addition to these changes, Stan Deal, Boeing Commercial Airplanes (BCA) President and CEO has retired, with Stephanie Pope appointed to lead BCA, effective immediately.

NEWS IN BRIEF

Emirates has entered into a SAF agreement with Neste at Amsterdam's Schiphol Airport. Over 2m gallons of blended SAF will be supplied to the airline's fuelling system at the airport over the course of 2024. The airline is also working with Neste to supply SAF to Singapore's Changi Airport within the next few months.

The Swedish Defence Materiel Administration (FMV) has awarded

Saab a two year contract to provide conceptual studies for future fighter aircraft – both crewed and uncrewed. The studies include a system of systems perspective, as well as technology demonstrations. (See Fighting for the Market, p16).

A UK-based company has successfully tested a key technology for future Space Based Solar Power (SBSP) stations in orbit. Space Solar,

based in Oxfordshire, was able to test its CASSIOPEiA technology by steering a wireless beam across a lab at Queen's University Belfast to turn on a light.

Statistics published by the FAA to coincide with International Women's Day reveal that of the 69,503 new student pilot certificates issued in 2023, a total of 7,102 were for female pilots. This was up from 5,566 female students in 2022.

Pratt & Whitney and the FAA are to collaborate with Missouri University of Science and Technology and the US Environmental Protection Agency to study non-CO₂ aviation emissions. The project will measure emissions from a Pratt & Whitney GTF engine combustor rig test stand using conventional Jet A kerosene and 100% SAF made from Hydroprocessed Esters and Fatty Acids Synthetic

Paraffinic Kerosene (HEFA-SPK), a biofuel derived from vegetable oils and animal fats and supplied by World Energy. Measurements will include non-volatile particulate matter and NO_x.

In an investor briefing on 21 March, Japan Airlines confirmed it will boost its widebody fleet with an order for 21 Airbus A350-900s, 11 A321neos and 10 Boeing 787-9s in 2024.

GENERAL AVIATION

G700 gets certificated



Gulfstream's G700 business jet received FAA type certification on 29 March, paving the way for customer deliveries of what the company refers to as "the most spacious aircraft in business aviation." The certification also confirmed two new performance improvements: a balanced field length take-off distance of 1,827m and a landing distance of 960m.

DEFENCE

UK to accelerate fielding of DragonFire laser weapon

Following successful firing tests, UK Defence Secretary, Grant Shapps MP has announced that the operational deployment of the UK's first laser air defence weapon, DragonFire, is to be accelerated with the goal of fielding it on Royal Navy warships by 2027 and even being fast-tracked to be sent to Ukraine to assist

in defending against Russian drone and missile attacks. With MBDA as the prime, and Leonardo, DSTL and QinetiQ partners on the 70kW weapon, the project is an example of a new Integrated Procurement Model at the UK MoD, designed to accelerate the fielding of high technology to the front line.

Serbia is to become the latest customer for France's Dassault Rafale fighter – with 12 to be acquired in a €3bn deal to replace its ageing fleet of MiG-29s. A firm contract is set to be signed in two months.

NASA has approved plans to send the Dragonfly multirotor drone to explore Saturn's largest moon, Titan in 2028. Arriving in 2034, the eight-rotor drone will fly in the dense

atmosphere of Titan to search for traces of life.

Dutch start-up, Electron Aerospace has unveiled an updated design for its five-seat, all-electric aircraft, which it intends to bring to market in 2028. The company believes recent developments in battery technology will give the Electron 5 a range of up to 310 miles (plus safety reserves of a further 150 miles) and a cruise speed of around 200kts. The redesigned

AEROSPACE



Bauhaus proposes hydrogen concepts

During a symposium in Berlin on 12-13 March, scientists from the Germany's Bauhaus Luftfahrt aviation think tank presented three designs for hydrogen-based concept aircraft aimed at different market segments. The three airliner proposals will now be used to assess the fundamentally new aircraft architectures needed to capitalise on hydrogen-powered flight.

airframe now boasts canards and a cruciform-configured tail, plus a long wingspan and twin pusher engines.

Embraer has revealed that it is working on expanded missions and roles for its C-390 Millennium airlifter, including a Maritime Patrol Aircraft (MPA) version with the Brazilian military and a civil freighter variant in partnership with Brazil's postal service. The latter co-operation also includes exploring opportunities for

cargo versions of its E190 airliner family.

The government of Pakistan has officially launched a tender for the privatisation of its flag carrier, Pakistan International Airlines, with a deadline for expressions of interest in a majority share due by 3 May.

The first former Swiss AF F-5E destined for the US Navy was collected from Emmen AFB by a C-130 on 16 March. The

aircraft will be refurbished before re-emerging as an F-5N+ for VFT-402. In total, 18 Swiss F-5Es and four F-5F two-seaters will become F-5N+ and F-5F+s for the USN aggressor units.

The planned launch of a Russian Soyuz from Baikonur Cosmodrome, Kazakhstan, containing three cosmonauts on 21 March, was aborted just 21 seconds before lift-off, due to a 'voltage drop', according to Roscosmos.

DEFENCE

Lockheed Martin reveals Mako mini-hypersonic missile

Lockheed Martin



Revealed at the US Sea Air Space 2024 symposium in April was this Lockheed Martin proposal for a small form factor air-to-surface hypersonic missile, Mako, that could be carried internally by an F-35. The multi-mission Mako, originally developed from the USAF's Stand-in Attack Weapon (SiAW) programme, could also be carried by other platforms, including the F-22, F-15, F-16, F-18 and P-8.

GENERAL AVIATION

UK issues Future of Flight 'action plan'

The UK Department for Transport has published a Future of Flight action plan, emphasising that 'drone technology' could boost the UK economy by £45bn by the end of the decade. The report predicts that "flying taxis, crime-fighting drones and critical 999 care deliveries could all be a reality by 2030." It sets out a roadmap for drones and electric aircraft in the UK that proposes

the first piloted 'flying taxi' flight by 2026 and regular services by 2028, regular drone deliveries by 2027 and demos of autonomous pilotless flying taxis by 2030. Other actions include allowing drones to operate BVLOS and advising aerodromes on how to operate as vertiports. (See 'RAeS publishes groundbreaking Advanced Air Mobility safety paper' p52).

AEROSPACE

Japan mulls launching hydrogen airliner project

Japan has announced that it aims to develop a clean-sheet hydrogen-powered airliner, with the nation's government pledging to support projects with a view to having it market-ready by 2035. The 5tn Yen (around \$30bn) necessary to design and build the aircraft is expected to come from both private and public companies

with the government setting up 'sovereign climate transition bonds' to help promote cleaner technologies. The last Japanese airliner, the Mitsubishi SpaceJet (originally the Mitsubishi Regional Jet), only received 50bn Yen (\$330m) in government funding with the balance provided by Mitsubishi Heavy Industries.

SPACEFLIGHT

India glide tests reusable spaceplane



A sub-scale prototype of India's proposed reusable spaceplane successfully completed a glide landing test on 22 March. The 21ft-long Pushpak was dropped from below a Chinook helicopter at 15,000ft and autonomously landed on a runway 2.5 miles away at the Indian Space Research Organisation (ISRO) Aeronautical Test Range in Karnataka, coming to a halt using a brake parachute.

NEWS IN BRIEF

Eve Air Mobility has won an order for up to 50 of its Eve eVTOL air vehicles from AirX, Japan's largest helicopter charter operator. The deal breaks down into 10 firm orders and options for a further 40.

Boeing has issued a detailed technical rebuttal of a whistleblower's claims that the 787 Dreamliner has fuselage structural failings that could make

it break up in flight. The company said it was "fully confident" in the aircraft and "claims about the structural integrity of the 787 are inaccurate."

Dubai International Airport experienced severe disruption in mid-April with around 300 flights cancelled and arrivals halted after the UAE was hit by the heaviest rainfall in 75 years – with runways and taxiways at the airport

left submerged. The airport authorities have warned that recovery will take some time.

The USAF Test Pilot School and DARPA have announced a breakthrough in AI machine learning, with the F-16-derived X-62A VISTA demonstrator flown with a safety pilot used to test AI dogfighting skills against piloted F-16s in a series of air combat trials at Edwards AFB.

ON THE MOVE

CCO of GE Aerospace, John Slattery is to step down in June but will remain an adviser.

Birgir Jónsson, CEO of Icelandic carrier PLAY, has resigned with immediate effect and will be replaced by one of the airline's largest shareholders, Einar Örn Ólafsson.

Lilium has appointed Johan Malmqvist as CFO.

He was most recently CFO at EV manufacturer, Polestar.

One year after entering training, the 2022 class of ESA astronauts, Sophie Adenot, Pablo Álvarez Fernández, Rosemary Coogan, Raphaël Liégeois and Marco Sieber graduated on 22 April – along with Australian astronaut candidate Katherine Bennell-Pegg.

News Analysis

DEFENCE

Iran launches combined drone, cruise and ballistic strike against Israel

Tim Robinson

On the night of 13/14 April, in retaliation to an Israeli air strike that killed a senior Islamic Revolutionary Guard Corps (IRGC) commander in Damascus, Syria, Iran and its proxy forces launched a complex attack of between 300-350 one-way Shahed 136 attack drones, cruise and ballistic missiles against targets in Israel. In response to intelligence of an imminent strike, Israel had put its forces on high alert and scrambled its air force – with over 99% of the incoming missiles and drones being intercepted by air, ground and sea defences. Virtually all the weapons were intercepted before entering Israeli territory, according to the Israel Defense Forces (IDF).

The attacking mix, launched by Iran and its proxy forces in Yemen and Iraq, consisted of around 170 Shahed 136 one-way attack drones, 120 medium-range ballistic missiles and 30 land-attack cruise missiles in a complex strike that reportedly took lessons from combined Russian missile and drone attacks against Ukraine, Tehran having sold the Shahed drone to Moscow.

In addition to the IAF F-15s, F-16s and F-35s, the raid also saw US, UK and Jordanian fighters engage and shoot down the drones and cruise missiles en route to targets in Israel. USAF F-15E Strike Eagles forward deployed from Seymour Johnson AFB and RAF Lakenheath shot down around 70 drones – with the squadron commanders of the 335th FS and 494th FS being personally congratulated by President Biden for their efforts in assisting in the defence.

RAF Typhoons from RAF Akrotiri, Cyprus normally involved in anti-ISIS Operation Shader missions were also part of the giant air battle – bolstered by additional Typhoons pulled from the NATO Air Policing deployment in Romania covering the Black Sea – with the RAF jets reportedly shooting down between 10-20 Shahed attack drones. Jordanian AF F-16s also engaged an unknown number of targets that had violated their territory.

Some idea of the intensity of the raid is given by one IAF reserve fighter pilot, who described the night as “the most complicated mission I’ve done in 20 years in the air force, knowing that if there is a missed target, maybe it blows up in Israel,” to the *Daily Telegraph* – telling the paper it was “*Star Wars* meets *Top Gun*” due to the number of explosions and missile launches going on around him. IAF pilots shot down 25 out of 30 cruise missiles launched against Israel, according to the IDF.

Missile defence

As well as interceptions of low-flying cruise missiles and drones by airborne fighters, medium-range ballistic missiles were intercepted by Israeli and US BMD missile systems, including David’s Sling, Iron Dome, Arrow 3, Patriot and the SM-3 aboard US Navy warships. It was the first combat use of the SM-3 ballistic missile interceptor, with two US Navy warships, the USS *Arleigh Burke* and USS *Carney* in the Eastern Mediterranean firing between four and seven SM-3s at inbound missiles targeting Israel. The attack also saw what is believed to be only the second combat use of the Arrow-3 exoatmospheric anti-ballistic missile to intercept targets outside the Earth’s atmosphere.



IAF F-15I after returning from a combat mission on 14 April.



FLIR footage of Iranian Shahed-136 drone being shot down by an IAF fighter.

Five ballistic missiles got through the combined layers of air defences with four landing on Nevatim Air Force Base where IAF F-35s are based and causing minor damage to the runway and a couple of empty hangars. US officials, meanwhile, said that, of the 120 ballistic missiles fired by Iran, around half failed on launch or crashed without being intercepted.

The only casualty of the night was a seven-year-old girl injured by shrapnel from an intercepted missile in the southern Negev region.

Summary

Following the attack, while Washington had privately urged restraint, given the success in defending against the raid, the international help given and the lack of casualties, on 18 April, Israel carried out a limited missile strike on Isfahan airbase, where Iranian AF F-14 Tomcats are based. Short-range drones were also reportedly used in the attack, with a SAM site defending the airbase having its radar destroyed.

For its part, Iran has declared the operation a success and indicated that it will take no further action beyond this, unless Israel retaliates further.

By the Numbers

Understanding the world of Aerospace through data

Fifth-generation fighters in service around the world

Stealth platforms go mainstream.

LOCKHEED MARTIN 
F-35



Australia
60



Denmark
4



Israel
39



Italy
23



Japan
36



The Netherlands
26



Norway
30



South Korea
38



United Kingdom
34



USAF
234



United States of America
USMC
112



USN
30

LOCKHEED MARTIN 
F-22



United States of America (USAF)
234

 **中航国际**
AVIC INTERNATIONAL
J-20



China
208

 **SUKHOI**
SU-57



Russia
22

Pushing the Envelope

Exploring advances on the leading edge of aerospace



Robert Coppinger

Titanium 3D printing and repair

Additive manufacturing, or 3D printing as it is more commonly known, has long been touted as a new way to produce lighter, stronger components for the aerospace sector. The obstacle for the processes, of which there are several now, is that the sector requires long and difficult testing procedures and certification – and this safety regime was established with traditional manufacturing techniques in mind.

However, a new project could lead to 3D printing being used for the certified repair of flight-critical parts, thanks to a potential certification solution known as a 'digital platform'.

This sees sensors embedded in the additive manufacturing process provide the platform's data which, in turn, contributes to that fabrication or repair procedure being certified. The digital platform would lead to the process being digitised for improved process control, explained Dr Chinnapat Panwisawas, Senior Lecturer in Materials and Solid Mechanics at Queen Mary University. That greater process control could then contribute to the ongoing certification of parts, either made or repaired, with 3D printing.

Anglo-Turkish project

Queen Mary University is a partner in the project that is co-ordinated by Turkish Aerospace Industries. The University of Sheffield Advanced Manufacturing Research Centre (AMRC) and Philadelphia-based Authentise, an engineering process management specialist, are also participating – the latter contributing its expertise in digital certification. In this largely Anglo-Turkish project, the team is joined by Turkish companies, Ion Industrial Metallurgy Research and Development Inc and ODTÜ Teknokent Yönetim, as well as Cambridge, UK-based Epoch Wires which manufactures superconductive wire.

Panwisawas' team wants to improve the fundamental understanding of the plasma direct energy deposition, or p-DED, material deposition process being used for the project.

Dubbed DISTOPIA (DISTorting the Aerospace Manufacturing Boundaries: OPERational Integration of Autonomy on Titanium), the project is funded by Innovate UK, under the UK-EUREKA SMART 'advanced manufacturing' programme. This sits within the main EUREKA intergovernmental network of 47 countries and is for international co-operation in

innovation. Organisations and companies applying through EUREKA programmes obtain research and development funding and support from national and regional ministries or agencies for international projects.

The overall goal of DISTOPIA is to develop an automated, cost-efficient, wire-fed DED 3D printing manufacturing and repairing method. The choice of titanium is due to this key aerospace material, used for the likes of engine turbine blades, being notoriously difficult to work with. It has one of the highest melting points for a metal at 1,600°C. As additive manufacturing is essentially about melting material, the plasma 3D printing process was selected for its very high energy.

Additive manufacturing processes range from powder beds using lasers to different forms of nozzle-fed deposition. Sometimes the nozzle feeds powder but for p-DED it is a special titanium wire. Panwisawas explained that the p-DED wire feedstock is larger than other processes at 0.25mm wide and this allows for a faster deposition that would be considered 'industrial scale'.

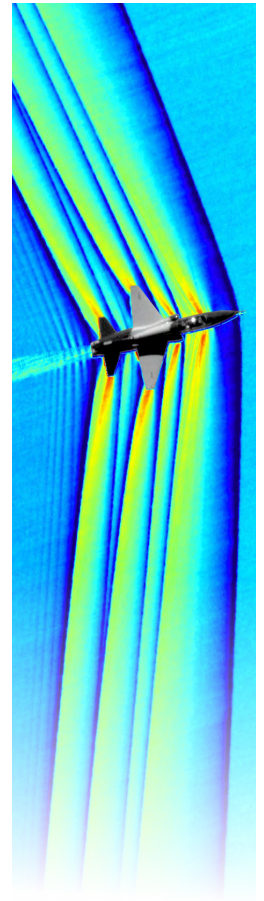
Repair shop

Panwisawas also emphasised the importance of the application to the repair of damaged parts and how the researchers want to "rejuvenate the part" and "extend the life of the component" to minimise industry waste.

The concept is to machine the damaged part to remove the area that is spoiled, leaving a portion of the part whose microstructure is consistent. The use of 3D printing then melts thin layer after thin layer onto the part to return it to its original design geometry, while also delivering a robust microstructure that is as strong as the original component.

Panwisawas envisages other aerospace materials, such as nickel and steel, also being used with p-DED and suggests that remanufacturing is another application expected to benefit from p-DED, extending the life of worn parts and contributing to the refurbishment of aerospace machinery.

Forty years after its beginnings as a laboratory curiosity, additive manufacturing's use is now widespread throughout many industries. DISTOPIA is another step in the ongoing development of 3D printing to slowly replace those traditional manufacturing techniques in many spheres of aerospace.



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THE OVERALL GOAL OF DISTOPIA IS TO DEVELOP AN AUTOMATED, COST-EFFICIENT, WIRE-FED DED 3D PRINTING MANUFACTURING AND REPAIRING METHOD

LETTERS

High flight to China

It used to be said that Chinese commercial aircraft were severely handicapped, compared to their Western competitors in that their regulations required them to be designed to serve Lhasa (capital of the Tibetan region) at an altitude of 3,700m. By comparison, the main design driver for Western aircraft was said to be Denver, Colorado in mid-summer at an altitude of 1,600m. Alan Dron's article on this subject [Can China break the airliner duopoly? – AEROSPACE April 2024] made no mention of this factor so I wonder if it is no longer valid (if it ever was)?

Pat Norris FRAeS

The three Horsemen of the total eclipse



Large numbers of private pilots chose to take to the skies in the US on 8 April to experience the solar eclipse from the air. Airports falling within the path of totality saw unprecedented increases in aircraft movements and the internet was flooded with images taken from the air during the rare occurrence but few were more impressive than those taken by the Horsemen aerobatic team, which flew its three North American P-51 Mustangs in formation as the Sun slowly disappeared behind the Moon.



From the RAeS photo archives

This May marks the 60th anniversary of Jacqueline 'Jackie' Cochran setting a new women's airspeed record of 1,429mph in a Lockheed F-104 Starfighter in 1964. This year is also the 90th anniversary of Cochran's participation in the 1934 MacRobertson Trophy Air Race from England to Australia and the intrepid aviatrix is seen here with co pilot, Wesley Smith, alongside their Gee Bee QED, before departure from Mildenhall, Suffolk. Sadly the pair withdrew from the race after the custom-made racer aircraft's flaps were damaged landing in Bucharest but Cochran's passion for speed was ignited. In 1937 she competed in the Bendix Trophy and also established her first female air speed record. At the outbreak of WW2, prior to the US joining the fight, Cochran was part of Wings for Britain, ferrying US-built aircraft to Britain – and, in doing so, she became the first woman to fly a bomber across the Atlantic. Upon arrival, she volunteered her services to the RAF, working for the Air Transport Auxiliary and later recruited other American women for the service before returning to the US to help set up the Women Airforce Service Pilots (WASPs). A post-war return to record-breaking flights saw her become the first woman to break the sound barrier (in a Canadair Sabre in 1953), the first woman to take off from and land on an aircraft carrier, the first to make a blind landing, the first to fly a jet aircraft across the Atlantic and the only woman ever to be president of the Fédération Aéronautique Internationale. At the time of her death in 1980, Cochran held more speed, distance or altitude records in aviation history than any other pilot.

ONLINE



Stuart Roxburgh What does the MEL say about that?

Nigel Foster That'll be expensive. Thank God for insurance!

Bill Sutton Must have had some serious momentum.

Worthy of celebration?



Response to 'Atlas goes from strength to strength - A400M celebrates 10 years in service.'¹¹

Jo Hunter How is that ten years old already?!

Steph Smith And I've been working on it for seven years now!

Nicholas Hill The A400M is a hugely controversial aeroplane - a pure political project. Yet, here we are, ignoring reality. Nothing you list couldn't have been done by an HP. 42 from the 1930s! So a transport can transport things? So what? Is it worth 'celebrating' a 20 year design gestation?

Oh Vienna!

Response to 'Austrian A320 tail sheered off in towing accident at Vienna.'

Adam Setchfield It's really impressive to rip half the stab off like that. That is a big repair job - it is possible either the stab or jackscrew might have punctured the aft pressure bulkhead of the fuselage.

Simon Westwood T-Cut - yes, T-Cut will sort that out.

Jasper Vd Heijden Just one word... how?

Jon Ostrower You have to really try, and then keep trying, to unintentionally total a commercial aeroplane like this.

Marilyn Dash You would think commercial air travel would be seamless by now, with near 100% reliability. But, no. It's like they are still trying to find new ways to scare travellers?

GA Design Competition



Response to 'RAeS General Aviation Design Competition winners.'

David J Pilkington A few points:

1. "A significant drawback with this design, however, was the location of the upper wing which would limit the all-important visibility during aerobatics." I disagree as the upper wing is behind the pilot's head.
2. "The best handling aircraft modelled and flown in an X-Plane simulation proved to be a very close competition between the team DAS' DA9 Hawkmoth and the team MIST Aerobat, with team DAS just having the edge." The DA9 is the only one with a decent size fin and rudder!
3. Did any team assess the spin recovery behaviour? I doubt it, as they all appear unsatisfactory to me!



Looking to the future

Response to 'If you were giving a lecture about the future of flight, what would you talk about?'

Pieter Johnson How AI and the use of sensors and data are changing the sector.

Chris Crockford Zipline in Africa, Boom Supersonic test in the US, Manna Drone Delivery in Ireland, Matternet in Berlin, Swiss Windracers in Antarctica, Vertical Aerospace and Altitude Angel in the UK.

Clem Newton-Brown The need for new vertiport infrastructure to support the promise of AAM. At Skyportz we aim to break the nexus between aviation and airports.

Jeremy (Jam) Hartley The importance of collaboration and acceptance within local communities. In order to see new aircraft and their services, as outlined by Chris Crockford and the vertiports mentioned by Clem Newton-Brown, everyone needs to be informed. Whether it's talking about the economics, technology or safety, the general public needs to understand all aspects before this new industry starts to scale up.

Also remember that future flight doesn't just mean eVTOL and urban air mobility. It also includes new fuel/power sources, airspace management and even spaceflight. Lots to cover but, like the rest of us in future flight, we're just starting to scratch the surface of what aviation will be like in the future!

The Boeing effect

Response to 'In the latest issue, Scott Hamilton asks how Boeing can get back on track.'

Ashraf Miah A great summary of Boeing's current woes and with some context on what it means for its future programmes. I think unless Boeing comes close to committing to a new single-aisle programme, Airbus will not commit unless it 'has to'.



Winkle reviewed



Response to 'One of the UK's leading test pilots, Dan Griffith, reviews Paul Beaver's biography of Eric 'Winkle' Brown.'^[12]

@Manonthefence A great review. When I get time, I want to compare the book with Winkle's 'own' (ghostwritten, I know) books. As a fellow adoptee, I have my own theories on why he denied his English roots. He was a Scot by any measure, just born in England by chance.

Space Command



Response to 'Has Space Command got a PR problem?'^[13]

@stephen_howell6 The combat command without any weapons?

@WriteBenSkipper Yes, 100%. The heavy use of buzzwords in its early days not only killed interest but diminished the overall mission. KISS [Keep it Simple, Stupid] was completely ignored by senior figures at the time as they thought buzzwords would somehow sell the wider mission as edgy.

@cpl43uk It is partly because all the general public hears about is astronauts, rockets and Mars. Space today is rather boring in its everydayness and news teams love a good explosion-in-waiting.

@ChrisUK27 Misunderstand the importance of space at your peril.

Catching up with Korea



Response to 'Korean KF-21 making every fighter programme in the world look slower than an asthmatic ant with some heavy shopping? Now doing AAR testing!'

@savov_jorro Do you think the boom AAR could hurt eventual future sales compared to if they went for probe-and-droge?

@agenmossad They have that option in design. At least that was the plan several years ago.

@pileftun Yes, but the KF-21 uses pretty much everything from off the shelf. Its engine, radar, fly-by-wire, etc have already been developed, tested and proven.

@FacelessManTwit Yes and no. Off-the-shelf components: engine (US), ejection seat (UK), EO-TGP (Korean), EW (Korean). Brand new: FBW (First implementation of Korean FBW), AESA radar (Korean), avionics (Korean), IRST (Korean software, Italian hardware).

Pilot mental health

Response to Can AI be used to identify psychological issues among airline pilots to prevent a repeat of tragedies like Germanwings?^[14]

@wildbluejester In-condition monitoring of flight crews is a super hot potato, even hotter than the notion of cockpit video recorders.

@SafetyAero How is AI going to determine that the pilots' union has so much sway over job retention that the doctors dealing with the Germanwings FO were cowed into submission when they should have grounded him when it was obvious he was not fit to hold a licence? Commercial pilots' medical records should be available to the applicable aviation authority freely and instantly from GPs. That's what would have prevented the crash.

Bad day at the office?



Response to 'Even Kelly Johnson had off days! His Lockheed CL-760 Light loss out to OV-10 Bronco.'^[1]

@IanPsDarkCorner Even my basic understanding of aerodynamics is going 'erm?'

Multi-tasking to the max



Response to 'Droneliner depicted air dropping supplies while tanking F-35s AND acting as an AEW platform? It's an Ultra High Value Asset. Shoot it down and you basically win the war.'

@JPPFRUS While they are at it, why not a simultaneous bombing and air-air capability? They lost a serious opportunity there. Or how about a submersible VTOL version?

@UKDefJournal With no ability to launch Trident or function as an ice breaker? Pointless.

@realcni Is the kitchen sink also on board?

@stephen_howell6 It's nice to see Thunderbird 2 has had a revamp!

@timdavies_uk This happens every so often, a promise of all things to all men. Rational thinking happens soon after and it becomes a tanker. When I was with Aeralis the RAF kept asking us if it could be a fuel truck, a drone carrier, a trainer, a fighter. Me... "No!"

@paynenotes1 I know I'm a bit of an armchair General but surely in a war we need a range of reliable things, which do what they do really well, and lots of them.

@AG46353940 Jack of all trades, master of none.

1. www.aerosociety.com/news/atlas-goes-from-strength-to-strength-a400m-celebrates-10-years-in-service/
2. www.aerosociety.com/publications/book-reviews-april-2024/
3. www.aerosociety.com/news/uk-aims-for-the-stars-space-comm-expo-2024/
4. www.aerosociety.com/news/pilot-mental-health-can-ai-powered-psychological-assessment-help/

Fighting for the market



With Europe, the US and other nations around the world hoping to seize their share of military sales, Professor **KEITH HAYWARD** FRAeS looks at those trying to break into the global fighter market.

High development costs and technological complexity are just two of several barriers that make it hard for countries to acquire a world-class capability in the aerospace sector.

The traditional entry-level projects have been small airliners or light strike-trainers but, these days, ambitions are set to a higher level with an eye on at least approaching standards set by the leading aerospace powers.

The road ahead, even for some of the more established players, is hard and affected by some harsh economic facts. One of the latter, 'Augustine's Law', posits that each generation of aircraft is far more expensive than the last. More on this 'law' later, but the point is that aerospace is not an easy industrial nut to crack. Yet, for economic and strategic reasons, many states have tried and are still trying to break into the market.

Super military powers (the US, Russia and now arguably China) clearly have a pressing need to develop state-of-the-art combat aircraft. Nations in the second tier (the UK, France and India, for example) also have a long-established interest in maintaining extensive aerospace capabilities, even if that means through collaboration.

So, who are the runners and riders in the latest exercise to claim a share of the world fighter business? Here are the usual suspects and some wild cards:

The leading members of the usual suspects – France, Sweden and the UK – along with partners, Italy, Germany and Spain are all busy trying to launch next-generation fighters.

The British and Italian team, remnants of the Tornado/Typhoon teams, leads the pack in terms of conventional inhabited designs but with the added frisson of a Japanese partner.

► The latest artwork depicting the proposed configuration of Tempest.
Leonardo

▲ Concept art of a European Next-Generation Fighter (NGF) controlling a collection of remote carriers.
Airbus Defence and Space

► Dassault rendering of FCAS/SCAF next generation fighter.
Dassault

France and Germany are still linked together and Sweden, once associated with the British-led team, looks like going it alone – again. Plus, of course, there is a continuing interest in selling current-generation aircraft, such as Typhoon, Rafale and Gripen.

Team Tempest

The Global Combat Air Programme (GCAP), also known as Tempest, is perhaps the most interesting of the next-generation contenders, not least for including Japan as a major team member. The latter has sought and largely failed to develop state-of-the-art products but its latest Mitsubishi F-2 is not even up to European combat standards. On the other hand, the Typhoon (BAE Systems and Leonardo's in-production contender) is lagging behind France's Rafale in terms of sales. Thus, all the GCAP team members have powerful reasons to push ahead with the Tempest.

Currently, the partnership is fleshing out exactly how the co-operative programme is to be managed and the responsibilities carved up. The GCAP International Government Organisation (GIGO) has been established to lead the programme with the aim of delivering a supersonic, low-observable combat aircraft by 2035. Interestingly, the GIGO headquarters will be in the UK but official leadership will rotate between the three partners. It is modelled on the US F-35 Joint Programme Office. The expectation is that Japanese firms will get a good share of 'noble work' but one suspects that *de facto* technical leadership may lie with Warton.

Government backing seems equally positive. The UK has allocated £12bn to the project over ten years and both Italian and Japanese governments have made, as yet undefined, commitments to funding. The GCAP team, mindful of Augustine's Law and the fragility of long-term defence budget forecasts, stresses 'affordability' as much as technical quality. The target is to deliver GCAP faster than preceding projects and much cheaper. BAE Systems and the Japanese have reputations for 'lean manufacturing' that should keep production costs down but the Achilles heel could remain in a complex development phase.

If the team does deliver on time and even roughly on cost, it hopes to be first to offer an exportable 'sixth-generation' fighter. However, this may depend on Japan not dropping political obstacles in the way of marketing the product.

A major step forward occurred on 26 March when Japan approved plans to

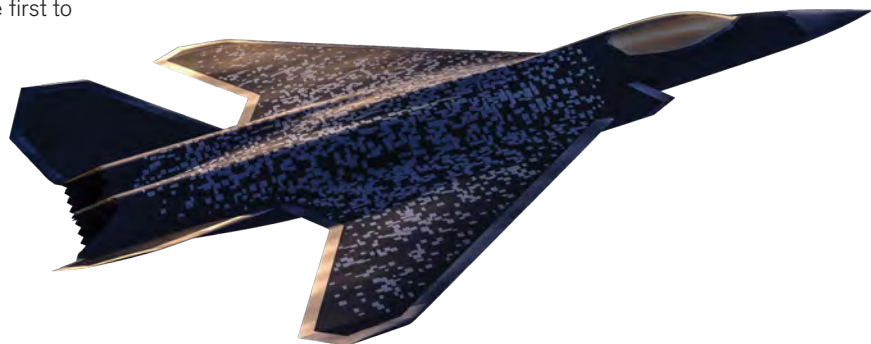
sell Tempest to other countries. However, officials emphasised that a strict approval process would be in place to 'adhere to our basic philosophy as a peaceful nation.' GIGO has pledged to promote exports and, with the Japanese government looking to relax legislative barriers to these third-party sales, the first contentious sale is awaited.

Europe's FCAS/SCAF

The renewed Franco-German military aerospace alliance to produce a Future Combat Air System (FCAS) has all the characteristics of a stately courtship but it is difficult to sort out who is courting whom! On the western side of the Rhine, Dassault always wants to run the show as it sees fit and has yet to deliver a collaborative programme since the Alpha Jet nearly 50 years ago. Getting this far has not been easy and not helped by Dassault's continuing success in selling the Rafale. That takes some of the pressure off France in any race to get a 'sixth-generation' fighter to the market.

Germany used to be an awkward partner, often blocking a clear run at potential customers. These sensibilities have eased of late, enabling more sales of Typhoon and generally reducing tensions with potential partners. Nevertheless, ensuring a predictable funding base out of Berlin may still pose problems. Airbus Defence and Space, the German partner, is not well placed to cope with a prolonged dearth of production. The German government's F-35 order, with little or no local industrial share, has emptied the kitty for an expensive new programme and the prospects for many more Typhoon sales are not great.

The French government is still funding the development of FCAS – or *Système de combat aérien du futur* (SCAF) as it prefers to call it. This is a combination of a sixth-generation fighter and 'loyal wingman' drones. There must be some suspicion that this is as far as French ambitions might extend, with a pause before entering fully into the 'sixth generation'. Buoyed by those Rafale sales, this might be a canny strategy for France, which would leave Germany waiting upon decisions shaped largely by French policy.



“

THE F-35, DESPITE ITS CONTINUING TECHNICAL PROBLEMS, COULD STILL BE THE MARKET LEADER INTO THE 2030S AS LONG AS A CUSTOMER CAN AFFORD IT AND IS POLITICALLY ACCEPTABLE TO WASHINGTON

DEFENCE

International combat aircraft industry

The Scandinavians

Having severed connections with the Tempest team, Sweden is focusing on deliveries of the latest version of the Saab Gripen. With a useful, if modest set of overseas sales, Sweden's perennial fight to maintain an autonomous military aerospace capability is likely to move into a sixth-generation contender. How long the country can sustain what is likely to be an expensive exercise remains an open question. The fallback may be another round of Gripen developments. In March 2024 Sweden announced it had commissioned next generation fighter studies from Saab.



Rest of the world

Elsewhere, several countries are in the business of developing fighters [see Fight Club p42], some better than others and several having had an extended gestation. India has just about got its much-maligned Tejas into service use, the Turkish Kaan has just started flight testing and Korea's KF-21 is in production.

To illustrate the difficulties in entering this market, the TAI Kaan has been 14 years in development. Türkiye and India might in the end be vulnerable to cost pressures and succumb to the temptation of buying off the shelf, with offset or co-production to keep their factories busy.

In both cases, politics might shape their sources – Türkiye has already lost access to the F-35, thanks to its purchase of a Russian air defence system but has been allowed to buy more F-16s. However, Turkish motives in producing the Kaan relate directly to promoting wider industrial interests which may trump economic realities.

Elsewhere, South Korea is gearing up to become the region's premier local arms' supplier. Russia has dropped back as a key source and China faces several political barriers. This leaves South Korea in a strong position, offering good quality, if not 'top of the shop' equipment, at a reasonable price and with governmental willingness to transfer technology to customers. If development moves

► RTX rendering of a notional tailless NGAD concept with CCA loyal wingman.

RTX

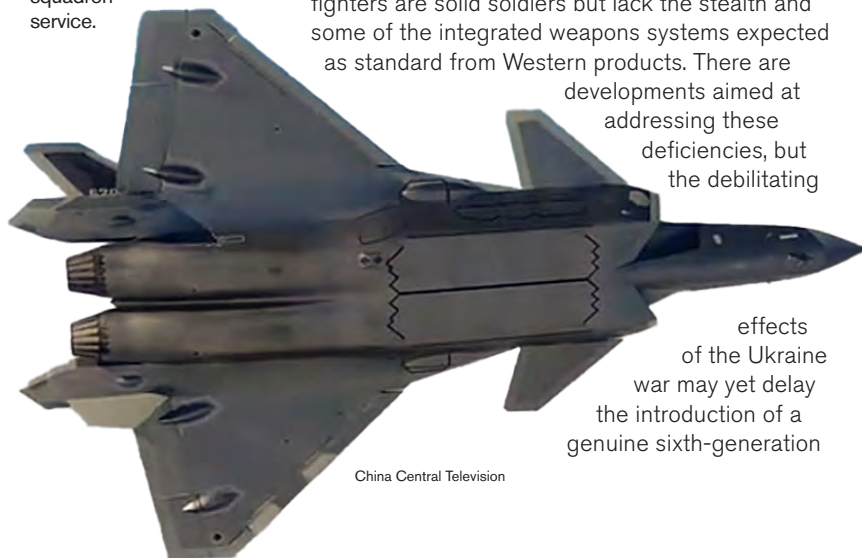
▼ A screen grab of the official video shared by Prof Dr Haluk Görgün, President of Turkish Defence Industries, showing the first flight of the TAI Kaan.

@halukgorgun/via X

▲ The fifth prototype of Korea's KF-21 Boramae completed the type's first aerial refuelling flight test on 19 March.

Defense Acquisition Program Administration

▼ A Chengdu J-20 stealth fighter attached to the Chinese People's Liberation Army Eastern Theatre Command. China is now thought to have at least 200 examples in squadron service.



China Central Television

smoothly, the KF-21 would fit very nicely into the South Korean catalogue.

US sets the standard

When all is said and done, the US still sets the technical and combat standards within the world fighter market. It still offers some fine earlier generation fighters – the evergreen F-16 continuing to find plenty of custom, more so now that smaller NATO powers look to meet the Russian threat.

The F-35, despite its continuing technical problems, could still be the market leader into the 2030s as long as a customer can afford it and is politically acceptable to Washington.

The next big one is the Next-Generation Air Dominance (NGAD) fighter, but, although this is shaping up to be yet another 'last man standing' \$15bn competition among US primes, all of the contenders have issues to resolve or other fish to fry. Northrop Grumman is busy with the B-21, Lockheed Martin is in low favour with the Pentagon for not delivering the F-35 on time and, of course, Boeing is in all sorts of misery.

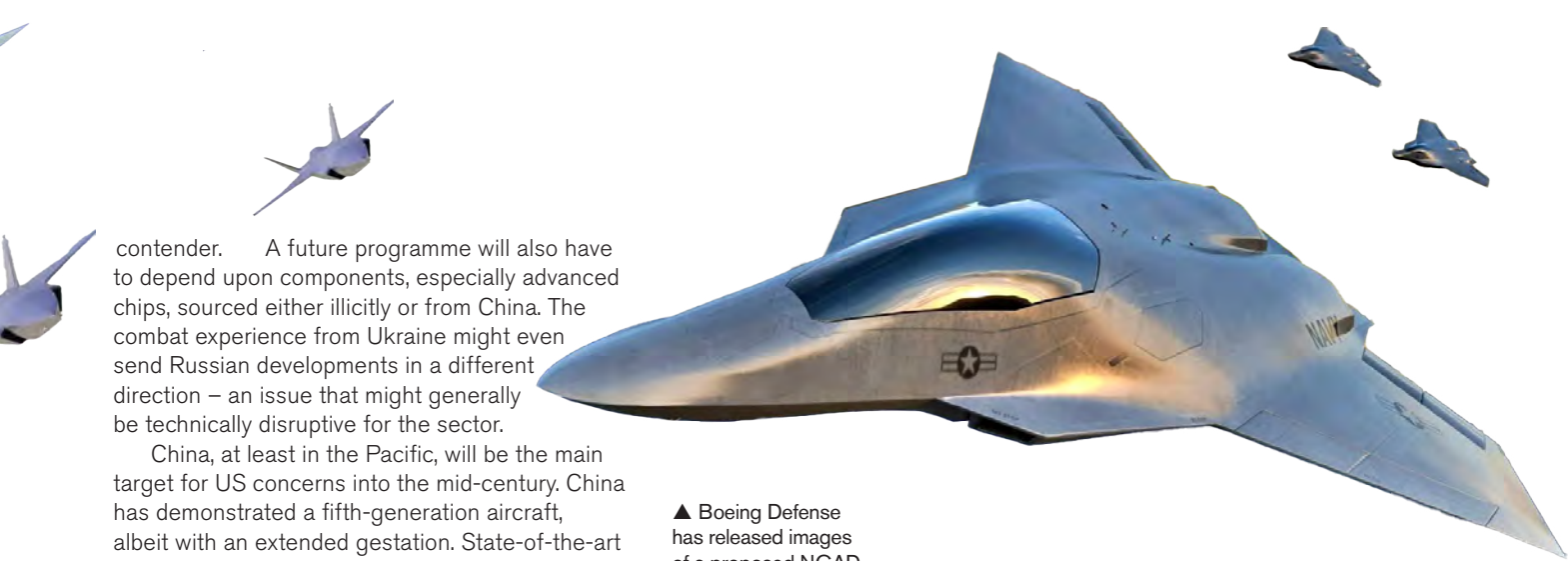
Unlike the F-35, NGAD will be an all-American project. The JSF collaborative experience might have been something of a deterrent to internationalisation but the number of simultaneous innovations demanded by the requirement demands full onshore development and production with assured control over new technology.

Russia and China

The Russian opposition, if that is what it will be, is something of an enigma. Its older generation fighters are solid soldiers but lack the stealth and some of the integrated weapons systems expected as standard from Western products. There are

developments aimed at addressing these deficiencies, but the debilitating

effects of the Ukraine war may yet delay the introduction of a genuine sixth-generation



contender. A future programme will also have to depend upon components, especially advanced chips, sourced either illicitly or from China. The combat experience from Ukraine might even send Russian developments in a different direction – an issue that might generally be technically disruptive for the sector.

China, at least in the Pacific, will be the main target for US concerns into the mid-century. China has demonstrated a fifth-generation aircraft, albeit with an extended gestation. State-of-the-art combat aircraft are a key feature in the ongoing modernisation of Chinese armed forces. As an established regional superpower, it has the incentive and emerging technological base to move into a higher dimension. The Chengdu J-20 will use the indigenous WS-20 engine in a bid to end dependence on Russian suppliers.

However, the quality of its top-of-the-line aircraft is still hard to evaluate. China's less sophisticated products are highly competitive in the 'bargain basement' world market segment but, with little or no recent combat experience, Chinese aircraft have only had brinkmanship games over the Straits of Taiwan as a means of testing battleworthiness.

▲ Boeing Defense has released images of a proposed NGAD contender. While the USAF and US Navy will share NGAD technology, the aircraft is unlikely to be built in the same numbers as the F-35.

Boeing Defense

Arabia has been linked with GCAP, although early publicity has receded with no evident movement yet. However, the operative word may be 'yet'. Again, much will depend on Japanese approval and exactly what the Saudis might offer other than money to the partnership.

Exotic developments, such as 'loyal wingman' uncrewed systems could provide opportunities for offset or partnership agreements, particularly as drone technology is widely available and based on commercial subsystems and components. This could be a very attractive proposition for the likes of Poland, or even India, looking to acquire something close to a sixth-generation aircraft, or at least some of the perceived benefits of development.

Market opportunities

The European Achilles heel of multiple programmes diluting resources, technical and financial, splitting the 'home' European market and fighting tooth and nail for American leftovers is with us again.

Not quite the same three-way competition, the three likely competitors will offer slightly different options. Japan gives GCAP a potential marketing edge into Asia but this is an untested coalition and might yet reveal potentially fatal sources of tension.

Still, the European situation hardly reflects any learning experience from the 1960s and the optimistic forecast of an integrated European defence industry and market. The F-16 will remain hard to beat, especially once the F-35 finally reaches maturity and moves into a regular upgrading sequence. However, it is hard to see NGAD in an exportable form.

Europe will also face strong competition from China and, increasingly, Korea for the less demanding customer – or those with shallower pockets. Building novel industrial coalitions could be the key to winning a good share of future markets. Traditional customers may also want to build a larger share of their purchases, both to defray the cost of a deal and to enter the aerospace business. This is a growing motive for Middle Eastern governments with an eye on post-oil economic development. For example, Saudi



▲ NGAD calls for a crewed aircraft with uncrewed escorts that will carry munitions, as well as conduct EW and reconnaissance missions.

Lockheed Martin

Cost vs quality

Affordability remains the elephant in the room. While the 'peace dividend' years have come and gone with a vengeance – recent Ukrainian industrial mobilisation and sword rattling in the Far East, let alone Gaza-related alarms, have increased world defence spending by an estimated \$200bn a year – there are still limits on how much individual states can realistically spend on weapons. This includes an upsurge in R&D associated with next-generation aircraft and missiles, not to mention complex defence infrastructure.

Once again, Augustine's Law lurks in the background, as technical complexity might continue to drive costs upwards. To some extent, improvements in both design and production techniques will act as a countervailing force.

However, looking at the economic outlook for countries, such as the UK, Germany and even China where the economy is looking shaky, money will be increasingly tight for new ventures, especially if cost escalation bites again.

● DEFENCE

Collaborative combat aircraft



Use them/lose them? Attritable drones

What does the future hold for attritable drones? **ED HUNT** investigates the future of collaborative combat aircraft, loyal wingmen and commercial off-the-shelf alternatives.

The concept of the 'attritable' drone or UAV has swung in and out of fashion. Prior to the Russian invasion of Ukraine, the leading concept was that military interest lay towards the higher-end of capability, albeit with a requirement for cost-effective procurement and sustainment. This platform would operate alongside traditional combat platforms but could be sacrificed if required and, crucially, without a major degradation of service capability or budget.

The Boeing Australia MQ-28 was arguably at the upper end of this, with the company suggesting it could perform the Unmanned Combat Aerial Vehicle (UCAV) 'loyal wingman' role alongside crewed fighters. Plus, its Commercial Off-The-Shelf (COTS) approach meant that the Royal Australian Air Force (RAAF) could shrug off a few losses.

Role definition

The subject remains somewhat clouded by basic problems of definition which reflect an underlying operational issue: what is the user actually trying to do and why?

Is it a mission attack, reconnaissance or a mixture of both? Standoff weapons are inherently attritable but their use has to be squared with the

mission requirement, not least because in reality they are costly and often in short supply (albeit not to the extent of crewed aircraft). They are not supposed to return to sender, which makes them simpler and of lower cost, but it does mean that once fired they are lost. Their 'attainability' rating is a function of the opportunity cost of their use.

At the other end of the scale, attrition of aircraft is, regrettably, to be expected during operations but is avoided where possible. A platform that could undertake ISR roles and return but that also places itself in a position to destroy a target should be a useful compromise.

However, does it in fact represent the worst of both? Can it be of sufficiently low cost but concurrently of necessary performance to identify and attack difficult targets without its loss being of consequence? Would a standoff weapon and a dedicated ISR platform not be a more useful and cost-effective approach, combining two items that have been designed purposely for such a task?

Laws of physics and finance

Between the 1973 Yom Kippur War and 1982 Lebanon conflict, the Israeli Defence Forces wrestled with the concept of UAVs, trading off how

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AS A VEHICLE, THE SMALL UAVS ARE SOMEWHAT CLUMSY AND RANDOM, AND CERTAINLY AN INELEGANT WEAPON, BUT THESE ARE INELEGANT TIMES



BAE Systems

Boeing Australia

▲ From left to right: Lockheed Martin Skunk Works' concept art showing an F-35A flying with various collaborative aircraft. The company has used this to illustrate its own vision for a future multi-layered crewed-uncrewed teaming architecture.

While the BAE Systems Concept 2 UCAV is supposed to be affordable, clearly they are not cheap and are to be used with care. Apart from its questionable value from a marketing perspective, the dropping of any reference to 'attritable' does suggest that industry and operators have both changed perspective.

A computer rendering of Boeing MQ-28A Ghost Bats flying with the Boeing E-7.

large and costly they should be versus the likely risk of their loss.

The mission envisaged was suppression of enemy air defences (SEAD/DEAD) and various comments suggest that they never quite managed to reconcile cost vs capability. It is notable that the modern IDF does not, apparently, operate much in the way of what might be termed an 'attritable' drone. In contrast, they have a large number of more capable, small and middle-weight uncrewed platforms.

Indeed, this 'attritable' approach has been questioned several times, including by this author and others, and it is somewhat surprising that the concept still generates interest and a degree of approbation.

While certainly a very useful capability, the basic laws of physics and finance suggest that it will not be possible. In order to have an aircraft capable of keeping pace with an F/A-18 or an F-35, it would need an engine of significant power and be of a size sufficient to endow Pacific ranges.

To avoid exposing the piloted fighter, it would also likely require a degree of low-Radar Cross Section (RCS) shaping, which is not a cheap exercise to design or build. In order to be useful, it would require on-board sensors that could track, target and engage high-end adversaries – all of which are expensive. True, its destruction would avoid losing a valuable crew but it is difficult to see how it could be considered low-cost, ie 'attritable'.

Turf wars

The last few years have also added another variable. For a host of different reasons – some rational, some emotional and some driven by the endless turf wars that characterise any large organisation – most militaries want to grab the high-end of the equipment spectrum for fear that their pet projects will be downgraded in favour of others.

This was a reason that the low-cost quadcopter has seen at best a mixed interest. It was beneath the dignity of an airman, it was too small for a sailor and many soldiers felt that they had better things to do. However, the success of these platforms against Russian armour is undeniable and has given pause for thought. As a vehicle, the small UAVs are somewhat clumsy and random, and certainly an inelegant weapon, but these are inelegant times. The odds of seeing an Israeli Merkava IV tank with a 'cope cage' (hastily assembled wire umbrella to stop small drone-dropped munitions entering the turret) seemed infinitely small until 12 months ago.

Such weapons are arguably the current apogee of the attritable drone, at least from a cost vs capability perspective. The war in Ukraine and, to a degree the conflict in Gaza, have pivoted military thinking back towards a return to mass. Enthusiasm among export customers for the F-35 continues (though, tellingly, less so for the US core customer) but the fact remains that a small and costly force, which is available only 40% of the time, is extremely fragile and of debatable utility.

Most of the new customers in Eastern NATO (and elsewhere) do not have a large UAV contingent and those that they do have would be dearly missed if lost. Yet, despite being the current flavour of the month, the small COTS UAV platform carrying a few kilograms of explosive is extremely limited in its utility. With the usual swing between offence and defence, these are also increasingly vulnerable to the growing presence of equally low-cost, anti-drone systems.

Suicide drones

At the other – and grimmer – end of the scale is the Russian use of larger UAVs, such as the now-ubiquitous Iranian Shahed. This is where the concept of 'attritable' becomes somewhat vague. These are colloquially termed 'suicide drones' (as much

● DEFENCE

Collaborative combat aircraft



as anything because it sounds dramatic) but are essentially low-cost cruise missiles. Compared to the previously celebrated Turkish Bayraktar TB-2, that was a genuine UCAV, these do not carry smaller munitions nor have any way of returning to their launch site.

Given that the definition of attritability must also consider cost, it is worth trying to determine the value of these four examples: MQ-28, TB-2, Shahed and quadcopter.

Boeing has not released the cost of its product but, based on the MQ-25 UAV (not dissimilar), a figure of tens of millions is likely. A TB-2 is less than \$10m, a Shahed is in the \$50,000 range and an armed quadcopter less than \$3,000, possibly as little as a few hundred dollars.

Of course, specific figures are only ever a guide to money changing hands and should be viewed as such. However, Ukraine is using Patriot missiles to shoot down the Shahed swarms, with each missile costing around \$5m. The maths is fairly obvious.

Swarm warfare

'Soaking up' enemy air defence systems is a less frequently discussed use of the attritable drone. This role has a pedigree, both to expend the platform as a target for an enemy missile but also to trigger the opposition to activate its radars and, hence, reveal their positions. A quick scan of the cost figures given above indicates the efficiency of doing so versus a crewed fighter (airframe only) valued at £100m plus.

This is where, perhaps more realistically, the 'attritable' drone may be a realistic prospect. The US and others are very keen on systems, such as the ADM-160 MALD (Miniature Air-Launched Decoy). This gives a fighter, such as the F/A-18, a means to 'test the water' ahead of itself by firing off what is essentially a target and listening for the enemy response.

It has the benefit (thanks to its fighter transporter) of starting with speed and altitude but the vehicle is

extremely basic and is not recoverable. It has also, as with virtually all weapons, climbed in cost from \$30,000 for the A model to over \$100,000 for the B variant.

Ukraine has announced an acquisition target of several thousand low-cost quadcopters and Russia shows no sign of losing its Shahed enthusiasm. Meanwhile, by contrast, the MQ-28 has not received a general order. If anything, the market appears to have circled back to the TB-2/Predator designs.

The high-performance attritable drone is not seeing the enthusiasm that had been previously envisaged. The outlay for a drone is less than a fighter and, hence, several UAVs may be bought for the cost of another crewed combat platform, but does the return on this cost really justify the spend? As stated earlier, if a force wants a UCAV to accompany traditional combat platforms effectively and over distance, it will not be cheap. The marketing images for GCAP, SCAF, NGAD, and the like, show a large platform flying apparently at speed and altitude. This is expensive. *Caveat user.*

Combat mass

This subject may be starting to tilt more towards the higher-performance, higher-cost/less-attritable end of the market and the term 'combat mass' has now started to replace 'attritable'. The difference is somewhat subtle but emphasises cost vs capability in terms of sufficient numbers for sustained operations. This correctly assumes that the nature of conflict will probably mean higher losses of these aircraft and hence 'mass' (size of the fleet) must reflect this. They are not intended to suffer attrition; they are intended to be used in sufficient numbers that mean attrition can be managed. Again, the distinction is subtle and may reflect more the manner in which they are integrated into forces and operations rather than the platforms themselves.

There is a historical precedent, with the USAAF's 8th Air Force in WW2 initially regarding its bombers as critical and the small number of escort fighters



▲ The Turkish Bayraktar TB-2 costs less than \$10m. Does that mean it is classed as 'attritable'?

▼ Russia has made extensive use of the Iranian Shahed 'suicide drones' in its war with Ukraine.





From left to right:

▲ General Atomics ASI Gambit family of drones.

The use of small sized drones has surged since the start of the war in Ukraine.

An XQ-58A Valkyrie demonstrates the separation of the ALTUS-600 small UAS in a test at the US Army Yuma Proving Ground in 2021.

as closer to 'attritable'. From 1944 this was reversed, with the bombers becoming useful bait and the escort fighters the prime weapon for destruction of the Luftwaffe. In the strategic sense, the goal remained the same but the weighting changed.

Thus, the emphasis is now on affordable combat mass for high-tempo operations, rather than a low enough cost to allow for losses. The outcome might be the same as it was in 1943-45 but the manner in which it was envisaged and executed has changed.

The move towards 'mass' will certainly result in more capable vehicles that are expected to survive in large numbers, rather than less capable alternatives that are expected to fall in quantity. In turn, this is likely to be grabbed by air force planning staff to justify more impressive aircraft to complement crewed fleets rather than poorer systems for control by ground forces. However, that is a battle as old as flight.

Current thinking

In several theoretical exercises conducted during late 2023 and 2024, the emphasis seems to have drifted towards a low-middling capability where subsonic UAVs, armed with a couple of weapons, were used in larger numbers.

The validity of this approach might have been demonstrated by the recent loss of Russian armoured vehicles around Avdiivka in Donbas. A range of weapons appear to have been used, including small drones with basic weapons alongside more traditional anti-tank guided missiles and probably mines. The loss of 20 to 30 MBTs and IFVs to three dimensions of relatively basic weapons is a very efficient use of resources, both in terms of damage inflicted and the low cost of equipment.

This success, combined with the concurrent high loss of costly crewed aircraft, adds weight to the US Army's decision to cancel yet another advanced attack and reconnaissance helicopter in the form of the Future Attack Reconnaissance Aircraft (FARA), part of the wider Future Vertical Lift (FVL) programme.

The destruction of armoured vehicles under these conditions has historically been the core of attack helicopters, but the explanation for the ending of development was that the skies had now become too dangerous for crewed (and by association) complex and expensive rotorcraft. The missions, according to the initial statements, will instead be fulfilled by a variety of connected land-air and space platforms and weapons, thus avoiding costly single-points-of-failure, such as a heavily armed and expensive aircraft.

There clearly is no sign of a consensus on this and we are far from a US or NATO-standard approach. Partially, this is due to the rapid pace of technology and variety of current conflicts where traditional and new weapons/assets are being employed in various ways.

The UK military has recently published its Autonomous Collaborative Platform (ACP) strategy, which mirrors various other defence documents and wider discussions across Europe. The key message is an effort to avoid a one-size-fits-all approach and, instead, focus on sharing technology and research across a variety of platforms that offer differing levels of capability. This can be co-ordinated through common communications and their control passed across users, including providing a high degree of collective autonomy.

Though the specific terminology will likely change, the plan envisages various main types – firstly, a low-cost, disposable aircraft to be procured in large numbers and that can be lost and replaced without much impact. Then there is a mid-level aircraft with on-board sensors and weapons that fits roughly in the 'attritable' or 'combat mass' segment where capability for targeting enemy air defences, alongside crewed aircraft, is possible over short ranges but overall performance is not much higher than current MALE aircraft. This example can be sacrificed without significant penalty but they are intended for repeated use over the course of weeks.

Finally, there is the high-end, survivable UCAV of which the BAE Concept 2 is a guide. This is intended to offer complementary performance to advanced crewed aircraft and, hence, will engender high cost. It offers combat capability rather than combat mass and, therefore, would likely be considered and managed in a similar fashion to a small fast jet where loss is to be avoided.

As stated before, a consensus is slowly forming but is a long way from being realised. The technological outputs of current air projects will have a key influence, as will distribution of budgets. However, the new RAF plan with its emphasis on segregation – and hence acknowledgement that the dreams of UCAV fleets in their hundreds are likely off the table – is probably a clear step towards a practicable plan for managing what will clearly become a key air capability as forces induct a new generation of aircraft over the next 20 to 30 years.

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THE WAR IN UKRAINE, AND TO A DEGREE THE CONFLICT IN GAZA, HAVE PIVOTED MILITARY THINKING BACK TOWARDS A RETURN TO MASS

● DEFENCE

Digital design for future combat systems

Digital engineering for next-generation air superiority

The digital engineering revolution has started but we still have a long way to go. **JONATHAN GLANVILLE** MRAeS, Technical Account Manager at Ansys, and Brig Gen **STEVE BLEYMAIER** (RETD), CTO for A&D at Ansys share their thoughts on this fast-moving technology.

The next generation of air superiority platforms will be distinguished from earlier ones by their substantial reliance on software-defined capabilities, such as scalable autonomy, collaborative combat, reconfigurable communications and comprehensive situational awareness.

These cyber systems provide decisive advantages but new software capabilities alone will not address the requirements of a next-generation platform. The physical systems of these aircraft must perform in tandem with software so that diverse missions can be accomplished against adapting adversarial capabilities. The challenges of designing such a platform are formidable and the complexity of interconnected cyber-physical systems threatens to extend timelines and inflate costs in an era where timelines and costs must be reduced.

The engineering and technology challenges are vast, necessitating the use of model-based software engineering, coupled with physics-based simulation and analysis. These technological approaches are not new. High-fidelity simulation models in the structural, fluid, electromagnetic and optical domains are now commonplace and pervasive throughout design. Component level models and analysis have been routinely

developed for over 50 years with multiphysics and co-simulation models rapidly following. Today it is possible to use simulation for detailed analysis at any level of design synthesis from the chip to the mission. Furthermore, modelling and simulation technology continue to advance. Co-simulation enables you to integrate embedded software models to run alongside the hardware models. Parametrisation of workflows and ever-increasing compute power have allowed for quick-running reduced order models that are used in systems simulations. System of systems modelling can then build upon the systems' model achieved through digital mission engineering (a subject covered later in this article). Yet these innovations are not enough for platforms as complex and cutting-edge as a next-generation air superiority platform. These modern, complex simulation workflows are often isolated and unconnected to the rest of the engineering disciplines. This leads to a lack of traceability and makes it difficult to maintain consistency between domains — whether it be requirements, software, electrical or mechanical design, test and evaluation or any other such domain. For these reasons, the potential of simulation for the development of complex platforms, such as fighter aircraft, has yet to be fully realised.

Change is needed

A fundamental change in how systems are designed, developed, tested and maintained is, therefore, necessary to create truly next-generation platforms. That change can be summarised as the adoption of a model-based digital ecosystem that includes all aspects of design and connects them through a traceable digital thread. Collectively, this is called digital engineering. The defence industry has already taken significant steps to develop a stronger understanding of digital engineering, and the US DoD has gone so far as to instruct (in DoDI 5000.97) its project managers to require that digital engineering and mission engineering are applied to the development of new programmes. This is obviously a significant inflection point but, in truth, the digital engineering revolution has only just begun.

Digital engineering

Although the general concept of digital engineering is not new, the term has shifted in meaning in recent years, due to an unprecedented demand for digitalisation. Here, we consider digital engineering as an integrated digital approach that uses authoritative sources of systems' data and models as a continuum across disciplines to support life cycle activities from concept through to disposal. Within this definition there are three key aspects:

- (a) The entire design is encapsulated as models.
- (b) A set of authoritative sources – to collate, manage and communicate the models and data in a trusted manner – is established.
- (c) The continuum of data shared between models must span the entire life cycle, maintaining that it is a singular, trusted and traceable connection. This is typically called the connected digital thread.

The digital thread is the connection between many engineering disciplines and their models and data, for instance, requirement, model-based systems engineering, model-based software design, electronic design (ECAD), mechanical design (MCAD) and model-based analysis. Through the implementation of a connected digital thread, information silos and unsynchronised efforts can be dispelled.

The potential benefits of digital engineering are especially attractive to aerospace and defence organisations. In defence programmes the total life cycle cost is often (approximately) divided equally between development and the combination of operations, maintenance and sustainment. However, the vast majority of cost is committed by the decisions made during the development phase. Therefore, considering the lengthy life spans of

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THE F-35 HAS OVER 8 MILLION LINES OF CODE AND FUTURE SYSTEMS WILL HAVE EXponentially MORE

▼ The Franco-German FCAS is making extensive use of AI during project development.

30-40 years or more, defence programmes are particularly sensitive to those early-decided cost commitments. Overall, the following four trends can negatively impact the scope, cost, schedule, performance and reliability of these long-life programmes:

- (a) Physical testing for performance, reliability and life is becoming increasingly expensive and limited in capability and effectiveness.
- (b) Unforeseen schedule overruns that reduce the programme's value over time.
- (c) Slow technology maturation/adoption and supply-chain complexity.
- (d) Hardened requirements in programme governance prevent necessary updates to the technology stack or operational technology.

Digital engineering facilitates discovering critical issues early in the life cycle. Improving the timeliness of such insights can help organisations avoid cost overruns across a programme's entire life cycle, while reducing risks to development cost, schedule and performance. In the following sections, we address how digital engineering can enable these critical, early insights. In particular, we will consider examples of mission-centric design, addressing multi-discipline problems, such as tightly integrated cyber-physical systems, and enabling test and evaluation (T&E) as a continuum throughout design.

Digital mission engineering

Digital mission engineering (DME) is the use of digital modelling, physics-based simulation and analysis to incorporate the operational environment to evaluate mission outcomes and effectiveness at every phase of the life cycle. During early-stage conceptual design, digital mission engineering



IBM Deutschland

● DEFENCE

Digital design for future combat systems

enables designers to verify the continuously evolving design parameters against mission success. As the design cycle progresses, the fidelity of models increases, hardening the digital evidence required for later certification. At the heart of digital mission engineering is a time dynamic geometry engine that calculates position and orientation of assets via propagation algorithms or external inputs. Given these dynamic positions and orientations, engineers can model the characteristics of sensors, communications and other payloads. The quality of these links, incorporating a wide range of constraining conditions and environmental effects, are determined to evaluate the mission outcome.

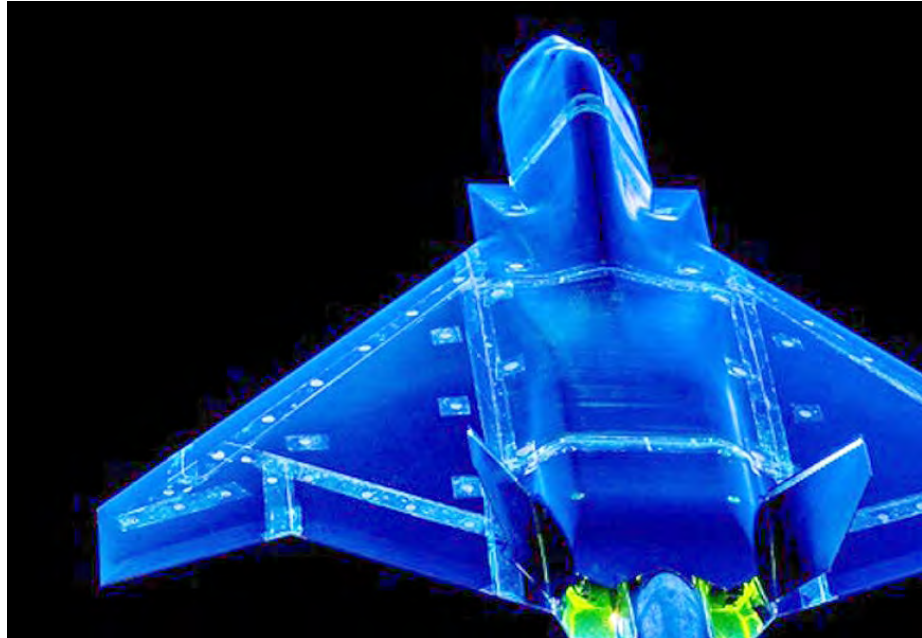
A concept of operations (CONOPS) is a record of the top-level performance requirements of a proposed system from the perspective of the individual operator of that system and, thus, the intent regarding an operation or series of operations. The CONOPS can be translated to produce a Design Reference Mission (DRM), which specifies the environment and situation of the proposed mission, including interactions between the system and the environment, other actors and well-defined measures that evaluate the outcome (and, thus, mission success).

Next-generation air superiority platforms will be an interconnected family of systems. Around the world, we see a future picture of a central crewed fighter aircraft supported by a mix of uncrewed collaborative systems and uncrewed co-operative weapons. The increased complexity of the operation can be managed by modelling and simulation. By digitising the DRM, the use of DME centralises the mission, directly linking design trades and decisions to CONOPS. Incorporated with digital engineering, this provides a direct link to engineering and physics data and models which enables the validation of system behaviour against requirements. Further to this, a mission-centric approach enables teams to rapidly iterate on requirements and design, continuously.

▼ MBSE integrates a descriptive modelling tool with other digital tools, such as schematic capture, mechanical assembly drawings, thermal analysis, physics mathematical modelling and simulation, as well as cost estimation.

Integrated software and physical systems

Thanks to advancements in semiconductor technologies, almost all modern systems use embedded electronics, and operating these components requires a tremendous amount of



software. The F-35 has over eight million lines of code and future systems will have exponentially more. Model-based software development environments enable the most advanced approaches to create safety-critical embedded software. These environments provide linkage to requirements management, model-based design, verification, qualifiable/certified code generation capabilities, automation of many tasks and interoperability with other development tools and disciplines. Key to the development of the cyber-physical systems related to autonomy, collaborative teaming and situational awareness is understanding the output of sensors and the quality of communications within a mission context.

It is the interoperability with other disciplines – for instance, combined software and physical system co-simulation early in the design cycle – that will assist the efficient development of deeply integrated cyber-physical systems. A relevant example is the development of autonomous systems that will be part of the air superiority family of systems. Designing an autonomous system will involve multiple disciplines that must be designed and tested coherently as a whole. Consider the example of a drone tasked to follow a leading aircraft, requiring the co-ordination of multiple disciplines in unison.

- The sensors team(s) will need to design and position the sensors on the vehicle.



Northrop Grumman

- Software teams need to develop software to interpret the feed from the sensors and provide controls to steer the drone. The software may also exploit AI which will need to be trained and validated.
- Mission or OA engineers need to ensure that the overall requirements of the system are met.

A model-based co-simulation approach can be applied to efficiently design and test the system. First, the scenarios can be created in a simulated world or environment. This world requires accurate underlying physics, for instance flight models, to propagate the drone through the world. High-fidelity, physics-based sensor models generate accurate image feeds from the simulated world. The output feed from the simulated world can then be used to validate (or train) the software with its specific control task. The resulting output of the software will feed back into the simulated world. Digital mission engineering can then determine if the Design Reference Mission's defined measures of performance are met. In this manner, the system, including control, sensors, and flight dynamics, is virtually validated against the CONOPS. Using digital engineering as the framework to co-ordinate intra-discipline communication and collaboration enables a team to de-risk and manage the complexity of the system early in the design cycle.

Test as a continuum

T&E data sources are traditionally made up of engineering calculations and experience, underpinned by live trials data. This data is collected into a body of evidence to establish pedigree, traceability and trust. Finally, the body of evidence is used to determine acceptance: is it fit for purpose, is it safe to use and is it what was asked for? Too much T&E traditionally occurs late in the design life cycle where problems lead to expensive fixes.

Additionally, T&E occupies a significant portion of any product development or programme budget. For example, flight tests are often repeated after the discovery of missed test points for a variety of reasons. For mission-critical applications, T&E plans are uncompromisingly detailed to ensure that even corner cases have proper mitigation plans for survivability.

Physical trials have traditionally been the mainstay of collecting T&E evidence. Since previous-generation munitions and countermeasures act one-on-one, they can be successfully tested this way. However, advances in the novel technologies required for next-generation air superiority, such as communications, autonomy or AI, mean that system of systems assets must be effectively tested. Future systems will include co-operative weapons, autonomous uncrewed systems and directed energy and hypersonic weapons, all of which will contend for dominance in a lightning fast operational

environment. With such a large degree of freedom, physical trials lose their statistical significance. There are other limitations to physical trials, such as overwatch and environmental concerns, that require an alternative to this traditional practice.

Considering T&E from the requirements and conceptual phase and continually gathering evidence and testing against the virtual operation environment has obvious benefits. Digital certification (or more accurately, mostly digital) is a requirement for any next-generation air platform. T&E has to evolve as it cannot cope with the complexity of novel technologies and system of systems assets. Physics-based modelling and simulation can provide digital-based evidence for acceptance. This is not new. Physics-based analysis has been used as an information source of evidence for many years, for example, to describe and understand the aircraft store release process. However, modelling and simulation incorporated within digital engineering, together with the management of model data and the connected traceability of those models, have the potential to transform test and evaluation activity fundamentally. Crucially, digital connectivity to developmental testing can ensure continuous verification and validation of models so that they are trusted.

Greater value is gained when model-based test and evaluation is considered as part of a comprehensive shift to the adoption of digital engineering. Model-based test and evaluation (MBT&E) centres on a mission-centric, CONOPS-based T&E virtual environment. Digital mission engineering can be used throughout the life cycle as a representative operational environment. Towards the end of the design cycle, during the process of acceptance, the MBT&E tools work in concert with T&E activities, such as test planning, execution and post-flight analysis, high-fidelity, physics-based root cause analysis, and test and physics data-driven virtual validation.

Summary

The complexity of next-generation air superiority platforms will grow exponentially, compared to current platforms, due to technological advancement in areas, such as communications, autonomy and AI. In the next generation, the speed at which you can deliver capabilities is destined to become a second great force.

As we have discussed in this article, the adoption of digital engineering will be essential to manage the complexity of next-generation platforms and their interconnected systems. In addition, digital engineering can transform the design process to dramatically accelerate delivery of new capabilities. This is why we believe that nations, individually or collectively, will not achieve their next-generation air superiority objectives without fully implementing digital engineering.



BAE Systems

▲ Although Tempest's final configuration has yet to be finalised, BAE Systems has been conducting virtual wind tunnel tests of notional designs.

● DEFENCE

Electronic warfare in the future battlespace



Intelligent EW Systems

A viable counter to stealth-based technologies?

Can we look towards machine learning and artificial intelligence technologies to create an intelligent electronic warfare system? Dr **DAVE SLOGGETT** thinks so.

It was in a speech to the House of Commons on 10 November 1932 that the prime minister of the day, Stanley Baldwin, uttered the oft-quoted words, "the bomber will always get through." The phrase was used in a wider-ranging address that was titled 'Fear for the Future' and was a prescient examination of the role of the

bomber and the difficulty of preventing attacks on a civilian population.

The speech echoed the thoughts of other air power specialists of the time, such as the Italian General Giulio Douhet in his work, *The Command of the Air*, and HG Wells who used his 1908 book, *The War in the Air*, to predict how aerial warfare

▼ China's J-16D electronic warfare aircraft was first seen sporting jamming pods in 2021. Often compared to the US Navy's EA-18G Growler, the J-16D carries at least three different EW pods on pylons under its wings and fuselage.





USAF MUSEUM

▲ The loss of an F-117 Nighthawk to Serbian forces in 1999 exposed the weaknesses of stealth technologies and heralded a new era in air defence systems.

▀ Russia has claimed that combining the Khibiny electronic countermeasure system with the SAP-14 and SAP-518 active jamming stations has enabled its Su-34s to 'disappear' from enemy radar screens. Despite this, it has reportedly lost ten of the jets in February 2024 alone.

▼ The RAF's fleet of three Boeing RC-135 Rivet Joint EW aircraft are in constant demand.

would destroy cities and result in the collapse of human civilisation.

Baldwin's thoughts were confirmed during the Blitz on London. Despite the heroics of the RAF during the Battle of Britain and the invention and timely deployment of radar, history shows that many bombers still reached their targets. However, in this fast-moving technological world, does this maxim still apply?

Necessity is the mother of invention

Today's air defence systems are a far cry from the system deployed in the late 1930s. The patchwork quilt of systems that Ukraine has managed to knit together with the help of donations from across the Western world, working in conjunction with its indigenous capabilities, is testimony to the art of the possible. *Mater artium necessitas* (necessity is the mother of invention) applies.

The Russian air force (VVS) knows this to its cost. While establishing precise figures for losses is difficult, it is clear that February 2024 has been a difficult month for the Russians. Some of its most essential and modern aircraft, including a reported ten fourth-generation Su-34 Fullback combat aircraft, have been lost in combat to Ukraine's air defences, as well as high-profile assets, such as two A-50 Mainstay AEW platforms and an IL-22 Coot-B flying command post.

This should come as little surprise to the Russians. After all, they arguably pioneered the development of the current generation of air defence systems, such as the S-300 and S-400 systems. So powerful are these systems that they have seen a new entry to the already vast lexicon of terminology used in the military world: Anti, Access, Area Denial (A2AD).

The introduction of these capabilities, alongside a much wider networked approach creating integrated air defence systems (IADS), makes the threat posed by mobile Russia air defence systems even more challenging. What in the 1980s was already a high intensity air defence environment for NATO to operate has become even more difficult.

This goes to the heart of the question. When faced with such an integrated capability, can the bomber still get through – even if only to operate in the role of close air support to ground forces or in a stand-off role using long-range precision-guided munitions? Gone are the days when the bomber's target was major cities in an attempt to destroy a population's will to fight. This has been reaffirmed in Ukraine.

This is a pertinent issue for the developers of the next generation of fighter systems. Given lessons emerging from the conflict in Ukraine, how can the survivability of these aircraft be increased? Does the continued reliance on stealth technologies still apply? Or are other solutions worthy of detailed exploration?

Any detailed analysis of the subject shows that stealth only goes so far in helping increase platform survivability and provides some valuable insights. Another well-established maxim in the military world is that for every measure (read 'stealth') there is a countermeasure. However, the issue with this idea is the balance of investment argument. Ideally in the measure-countermeasure cycle, the cost to your potential adversary to counter the deployment of technology should be significant.

Today, stealth technologies face a networked, multi-static and mobile IADS, mixed with highly mobile and easy to deploy man-portable air defence systems (MANPADS). The defence quickly gains an advantage and this is likely to be an enduring lesson from the Ukrainian conflict.



Stephen Bridgewater/PAAS

● DEFENCE

Electronic warfare in the future battlespace

Cognitive EW

So what is the next step for the offence? How is it possible to re-establish an advantage? Naturally, in today's fast-paced technology environment, it seems that looking at new forms of electronic warfare (EW) may provide a solution – more specifically EW systems driven by machine learning (ML) and artificial intelligence (AI) technologies.

Understandably, given this dynamic, China and Russia are investing heavily in these new areas where their command of the required micro-technologies is severely limited. This is an area where the West maintains a lead and where the evolution of cognitive EW systems offers a promising line of development.

Is 'Cognitive EW' just another fancy term used to sell military equipment to defence planners which provides a readily countered short-term gain? Or is it a solution that offers the side that commands it a tangible benefit and poses a serious problem for an adversary to complete the next stage of the measure-countermeasure cycle?



Northrop Grumman

Analysis of the loss of an F-117 Nighthawk over Kosovo in 1999 shows that Serbian air defenders were able to destroy the myth of stealth by innovating the way in which they used their radar

systems and other sources of intelligence to create a situation where the advantages of stealth technologies broke down.

Early warning of the incoming attack was provided by mobile phone from people near to Aviano Air Base where the F-117 was based. Flight times down the Adriatic were well known, so it was easy to estimate when the F-117 would be in the area. Approach routes into the operating area were also well known.

Using adaptive emission control (EMCON) procedures, the Serbs were able to avoid attacks by anti-radiation missiles on their radar systems and a

number of anti-aircraft missile launches channelled the F-117 into their killing ground. This was a manually intensive operation but it was a successful one, illustrating the measure-countermeasure maxim.

The weaknesses of stealth technologies, which are often expensive to deploy and maintain, had been exposed by a reactive way of using air defence systems. As such, the incident heralded a new era in air defence systems and it can be argued was also the catalyst for the development of the IADS systems in Russia. The aim was to pose a multi-directional threat to any F-22 aircraft that might be operating in the close air support role.

In the face of this highly networked IADS threat, the idea of using advanced technologies to deploy intelligent EW systems seems worthy of investigation. If the IADS threat comprises measures that mitigate against anti-radiation missiles should platforms carry an EW capability able to suppress adversary air defence systems?

In commenting on the losses of the Russian air force, several commentators have pointed to the lack of suppression of enemy air defence (SEAD) systems capability in modern fighters. This is surprising, given Russia's advanced EW capabilities.

In the land environment, Russia has invested in a formidable EW capability. It has even been able to threaten the UK Defence Secretary's aircraft as he flew to meetings in Ukraine. Russian EW systems also regularly cause problems in the High North for civilian aviation trying to use GPS for navigation.

Machine learning

However, despite Russian claims of using ML and AI technologies in this confrontation, the simple fact is that most of this is achieved through manual activity. That inevitably means that the defence systems are slow to operate and require a serious command and control overhead to achieve their results. From a NATO viewpoint, this is fertile territory for the use of Western ML and AI technologies. Cognitive EW systems, that can learn and adapt to an emerging Electro-Magnetic Spectrum (EMS), provide a viable solution that is hard to counter.

Traditionally, ML systems are heavily reliant on training data. This forms the backbone of the ML approach which seeks to match what it is observing to the training data. This is a process known as classification and involves the exploitation of a threat library which contains details of the signals drawn from intelligence sources.

It is a *sine qua non* of a cognitive EW system that it requires the threat library to be as up to date as possible. Ideally, if a previously unrecognised signature is observed, it should be immediately added into the threat library. This is not a simple



Ukraine weapons tracker via X

▲ A damaged Russian Army Podlet-K1 ground-based air surveillance radar in Ukraine.

◀ Northrop Grumman's Next Generation Electronic Warfare (NGEW) system was first tested in 2021 in collaboration with the AN/APG-83 Scalable Agile Beam Radar (SABR). Trials were flown during a USAF exercise to demonstrate full interoperability in a realistic and contested electromagnetic spectrum environment.

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THE
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INTELLIGENT
EW SYSTEM
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A PART OF AN
ELABORATE
DECEPTION
PLAN IS
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National Guard of Ukraine



MOD Crown Copyright

▲ A Ukrainian soldier with an Igla MANPADS in the Kharkiv region in 2022. The Serhiy Prytula Charity Foundation recently announced that its volunteers had adapted thermal imagers for the Igla systems, enabling operators to aim missiles at targets at night.

▼ Poland has recently acquired sufficient Common Anti-Air Modular Missiles (CAMMs) and launchers to equip 22 air defence batteries. The equipment is being provided by the British arm of MBDA. The UK deployed its own CAMM missiles to Poland shortly after the Russian invasion of Ukraine as part of its Sky Sabre air defence system.

process and updating a threat library in real time is, therefore, not easy.

The essential element of a cognitive EW system is its ability to learn what is going on in the EMS. While this sounds easy on paper, there are well known problems with ML and AI systems that must be confronted. Perhaps the most difficult of these is the process of learning. As humans, we do this all the time but for machines it is more difficult. It is not simply a case of updating the threat library with new information, such as intelligence on war mode operations of radar systems. The machine must also learn how, for example, decisions are made as to what is kept and what is discarded. A human may use both explicit and implicit knowledge to make such judgements but replicating that in a machine is not trivial. The potential for an intelligent EW system to be misled by data that is a part of an elaborate deception plan is not to be discounted.

Catastrophic forgetting

Another known weakness of contemporary ML solutions is known as catastrophic forgetting. This is where new training data replaces historical data without due attention to the significance of the historical training sets' relevance. The quality of the data in the threat library is critical. If this becomes compromised by false learning, the overall capability of the cognitive EW system will be severely diminished.

If intelligence systems have been able to collect a very detailed set of content, including the war modes, then the cognitive EW system will rapidly classify threats. This will help aircrews take a course of action that can minimise the threat to their platform.

However, if that intelligence picture is not comprehensive, the potential for the cognitive EW to be surprised exists. This is where ML and AI technologies offer the potential for the cognitive EW system to decide what is the best from a survival viewpoint.

Context is vital in all of this and what is known about how IADS are deployed and used to achieve their mission is equally important. Learning the course of action that IADS systems take in real time, as a threat emerges, is a crucial part of any solution.

It is clear that, to develop an operational cognitive EW capability, a solution must therefore be found to the problem of how to learn.

Inspired by leading research into cognitive neuroscience solutions that understand how the process of recall enforces memory, it turns out that the more times a specific memory is recalled, the stronger the synaptic ties inside long-term memory become.

Mimicking this kind of process where specific parts of a dataset is consolidated is a way forward. However, data points that exist outside the training dataset should not be readily ignored as they might be the key to a new set of learning that makes any cognitive EW solution even more adaptable, thus enabling it to stay ahead of the measure/countermeasure cycle.

This is one of the key challenges in making what might be described as the potential for using ML and AI technologies in a cognitive EW system a reality. Understandably, such an answer also solves a generic issue with ML solutions that offers the vision of real-time adaptive systems in a range of military applications' arenas.

Self-learning systems, of which a cognitive EW system is an example, will be at the heart of many military systems in the future. Almost everyone with any vision of this future agrees that ML and AI solutions offer a change that can pose a serious challenge to our potential adversaries.

They may also be the step change that rebalances the current threat and reinforces the notion that the aircraft will always get through – or, as in this case, continues to be able to operate in a hostile and complex IADS environment.

Sustainable, responsible and holistic

From recycled components to digital product passports, **ANDREW EADY**, Vice President Sustainability FCAS at Rolls-Royce, explains how the *FCAS Sustainability Strategy* reflects a broader shift within the defence sector towards responsible innovation.

The *FCAS Sustainability Strategy* is a forward-thinking initiative that aims to integrate environmental, social and resilience considerations into the development of the UK's next-generation combat air systems. It is fundamentally aligned with the broader goals of the UK MoD's *Climate Change and Sustainability Strategic Approach* and the RAF's ambition to achieve net zero emissions by 2040. However, it is important to remember that sustainability is much more than just decarbonisation and net zero.

When considering sustainability in defence, it can be useful to take the literal meaning of the word, ie 'the ability to sustain'. What are we looking to sustain? Well, for a defence operator, such as the RAF, it wants to sustain the freedom to operate and the freedom to modify in order to maintain operational and support advantage. It is critical that the defence operator and industry can continue to maintain access to finance, and to continue public and employee support and engagement.

One challenge is climate change. Extreme weather events can cause disruption across operations and support, with high temperatures affecting take-off performance, and flooding taking out a critical logistics node or supplier. Beyond climate change, the ability to use critical and high-value materials continues to be threatened as resources become scarcer and harder to secure.

In addition, we know many countries – and our customers – have ambitions of net zero by 2050. Between now and then, a high-carbon, fossil fuel dependent enterprise will soon be exposed to

increasing costs associated with carbon taxes and offset prices.

These examples are not exhaustive but all reinforce the need for an organisation – especially one in the defence sector – to embed sustainable practices into process, programmes and projects from the outset.

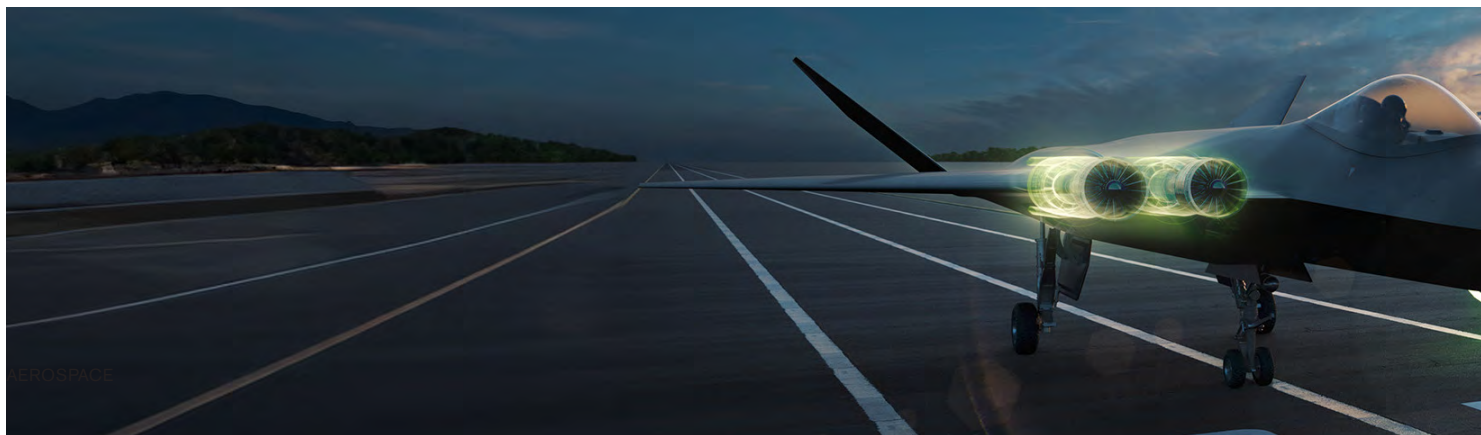
As the Future Combat Air System (FCAS) enterprise started to progress, it became apparent such an approach was needed to reduce the risk and improve resilience of the programme in the face of a changing world. On behalf of the programme, I was tasked with leading the development of the *FCAS Sustainability Strategy*, outlining steps to reduce carbon emissions and promote sustainable practices to ensure long-term viability.

Five objectives

Five strategic objectives form the backbone of the strategy which present opportunities to yield significant benefits for environmental and social sustainability. These consist of:

Improve enterprise resilience to climate change

The strategy begins with a commitment to resilience. Recognising the impact of climate change on military operations, the strategy aims to ensure that future combat air systems are robust in the face of the evolving threats posed by a changing climate. This includes designing equipment and support systems that can withstand extreme weather events and temperature fluctuations, ensuring that our



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A HIGH-CARBON, FOSSIL FUEL DEPENDENT ENTERPRISE WILL SOON BE EXPOSED TO INCREASING COSTS ASSOCIATED WITH CARBON TAXES AND OFFSET PRICES

customers maintain operational effectiveness in any environmental scenario.

Realise opportunities for enterprise resilience

Innovation is at the heart of the *FCAS Sustainability Strategy*. By embracing new technologies and approaches to material circularity, the programme seeks to not only mitigate the risks associated with climate change and resource scarcity but also to capitalise on opportunities for greater energy efficiency and sustainability. This objective focuses on integrating renewable energy sources, advanced manufacturing processes and digital technologies to create a more resilient and self-sufficient enterprise.

Maximise contribution to society

It is important to remember that sustainability is not just about climate change and net zero: there should also be a focus on contributing to the broader societal good and maintaining security for future generations. The strategy outlines plans to engage with communities, foster social value and inspire the next generation through educational initiatives in science, technology, engineering and mathematics (STEM). By aligning with the UK's Social Value Model and the UN's Sustainable Development Goals, FCAS aims to have a positive impact across society.

Minimise negative contribution to the environment

Environmental stewardship is a key pillar of the *FCAS Sustainability Strategy*. There is a shared ambition for the enterprise to be the world's first through-life net zero defence programme, achieved by reducing the ecological footprint through careful material selection, waste reduction and the promotion of a sustainability culture. By prioritising environmentally friendly practices and technologies, the strategy aims to minimise the negative impacts of defence activities on the planet and, in turn, for organisations within the enterprise to become even more attractive places for Gen Zs to want to work.

Maximise contribution to the national value framework

The final objective of the *FCAS Sustainability Strategy* is to ensure that the programme contributes

to the UK's economic and industrial growth and emphasises the importance of nurturing the next generation and creating green-skilled jobs. By channelling investments through the supply chain to areas of relative economic disadvantage, the strategy aims to stimulate local economies, reduce regional disparities, and promote inclusive and equitable growth. The focus on developing these areas not only creates job opportunities but also helps to ensure that the benefits of economic and environmental progress are shared widely. This inclusive approach is essential for building a resilient society where every region can contribute to and benefit from the UK's sustainability efforts.

Holistic approach

The *FCAS Sustainability Strategy* represents a holistic approach to integrating environmental and social considerations into the development of the next generation of combat air systems. It reflects a broader shift within the defence sector towards sustainability and responsible innovation.

With the aid of this strategy, we envisage FCAS to become the most successful and visible example of how UK defence can produce a world-leading sustainable product and, ultimately, improve operational support and supply chain resilience that directly influences the UK's future military capability.

The UK defence industry is already committed to developing innovative sustainable practices. Work under way includes exploring and testing sustainable and circular manufacturing processes to help pave the way to include more 'recycled' material in new builds and repairs, aiming to reduce the burden associated with the supply of critical and high-value minerals.

Digital product passports, a digital 'CV' of a component's history, are also planned on being demonstrated to explore themes, such as materials' traceability, as well as automating the monitoring of the supply chain carbon footprint. These capture data about the environmental impact of products, their composition, their production and history, and are a solution that is emerging in response to incoming EU legislation, initially for the battery industry. Rolls-Royce is currently conducting a feasibility study to understand the benefits this could bring to the aerospace sector.



● DEFENCE

Next-generation fighter sensors



Designing Tempest from the inside out

The next generation of combat aircraft are expected to be sensor powerhouses – gaining critical advantages not from sheer performance but from their capability to collect and fuse data and present key actionable information to pilots. **TIM ROBINSON** FRAeS reports.

What makes an outstanding fighter aircraft? A WW1 ace might have said turning capability and twin machine guns. A WW2 pilot might have added speed and time to climb. Post-war, these additions included radar and air-to-air missiles – and as the 20th Century drew to a close – low observability. Yet, in the 21st Century, information and the fusion of data is fast becoming the defining factor of fighters now on the drawing boards. This, it might be argued, was ever thus with cockpit visibility and the OODA loop in early fighters giving the pilot with superior eyesight the advantage of whether to press an attack or decline – but this now includes multiple sensors, both on board and off board, to allow a combat aircraft platform to perform 'simultaneous role' missions in highly contested environments.

This is the conclusion of Jonathan Smith, VP Capability, CTO, Future Combat Air (GCAP), Leonardo UK, on how the Tempest (or GCAP) future combat air system represents a 'paradigm shift' – even from the current fifth-generation fighters, such as F-22 and F-35. "One of the things I'm really interested in is how air combat is changing," he told *AEROSPACE*. "The thing for me now is not just multirole but simultaneous roles. Not just being able to role change to surface attack one day, air defence the next day then suppression of enemy air defences, it's about getting a package on a platform that can do all of those things simultaneously and being able to do that in the challenging threat context that we are now facing with anti-access area denial."

Paradigm shift

A former OC of the RAF's 17F Test and Evaluation Squadron on UK F-35B, with experience of Tornado F.3 and an exchange tour on the USAF F-22, including time as a Raptor instructor, Smith is uniquely qualified to bring a modern fighter pilot's perspective to the challenge and opportunities of developing the sensors and 'effectors' that will equip Tempest/GCAP in the future and what 'sixth-generation' fighters will bring to the battlespace. This next-generation radar/EO/ESM/EW system, called ISANKE (Integrated Sensing and Non-Kinetic Effects) and ICS (Integrated Communications System), promises to be as big a breakthrough for airborne sensors as the invention of the cavity magnetron for airborne radar or the invention of AESA, he said. "The paradigm shift that we're aiming for, in terms of a sixth-generation capability, is absolutely as groundbreaking as all those examples."

Critical to this will be a deeper integration of these sensors to fuse information that goes beyond what Leonardo describes as 'a load of federated sensors and then bringing that information together and displaying it in a common picture' that 'most people think of sensor fusion'. Says Smith: "Fusing information is technically not that much of a challenge. It's about fusing the right information from the right sensor with the right information from another sensor at the right depth to create something that otherwise wouldn't be available."

The future battlespace of 2040+

Smith notes that an evolution in fighter pilot tactics from 'WW2 big wings' or pairs for mutual support has been going on for a while now, with electronic systems and datalinks replacing the 'Mark 1 eyeball'. "Those sort of visual mutual support, line abreast formations had started to disappear some time ago."

However, helmet-mounted displays (HMDs) with other aircraft displayed as icons and datalinks have now started to replace the need for 'mutual visual support,' says Smith. "The real reason for that visual mutual support was to be able to check someone's 'six' but if you've got an integrated set of sensors that are doing that, which give you a 360° hemispherical look around the aeroplane (which is what fifth and sixth-generation fighters can give you), you don't necessarily need that. You can, therefore, gain an advantage from perhaps moving those platforms further apart and getting all the benefits that brings."

Smith also explains that, as well as an evolution in fighter tactics, the definition of 'fifth-generation' has changed. "The definition of a fifth-generation fighter when the F-22 came out included supermanoeuvrability and supercruise," he said, adding, "it shifted a little bit when the F-35 came out, and I don't think anyone would argue that an F-35 is not a fifth-generation fighter just because it doesn't have supercruise and supermanoeuvrability, like an F-22."

▼ Jonathan Smith, VP Capability, CTO, Future Combat Air, Leonardo UK, formerly the OC of 17 Test and Evaluation Sqn, RAF.



● DEFENCE

Next-generation fighter sensors

Smarts over brute strength

If supermanoeuvrability and sheer performance have become less important, then situational awareness, information processing and sensor fusion in fifth (and now sixth) generation fighters have leapt up the priority list for future fighter pilots. Says Smith: "The F-22 was an aerodynamic beast. It had big engines, a big wing to give it that energy but it wasn't just about that. It was about providing next-generation and significantly improved situational awareness to the operator so that they could see first and shoot first."

This capability to dominate the sky, not just in performance but through unmatched situational awareness, is being baked into Tempest/GCAP's DNA, explains Smith. "Tempest has been designed from the very outset to have deeply integrated sensing, effecting and communications to link multiple modes of sensing together. It's a paradigm shift in terms of enabling pilots to make the right decision but to make that right decision more quickly than an adversary, so providing the right information at the right time to enable decisions to be made clearly and correctly, efficiently and rapidly."

Though Tempest/GCAP is envisaged to be a large twin-engined fighter, with ample room for a powerful radar, modern technology now favours smarts over sheer strength. While the performance of previous radars relied on the size of the antenna dish, and more modern AESA radars the number of T/R (transmitter/receivers) that can be fitted to a flat plate, Smith explains that "it isn't just about brute strength. It's about doing things cleverly, harnessing things, like AI, increased autonomy, machine learning and advanced technologies. The power of a sensor doesn't necessarily have to come from the size or number of apertures you've got because there's always going to be a limit to that but the focus here is on making the software that is powering those highly capable sensors as good as it possibly can be".

However, Tempest/GCAP with its ISANKE will not just rely on radar to find, identify, track and lock the enemy. Instead it brings to bear a swathe of on-board and off-board sensors that will allow pilots to find and

defeat any enemy, no matter how hard they try to hide, deceive or jam. "It's about having that broad spectrum capability to be able to get round opponents' attempts to deny your kill chain by using other means and that, again, is the design ethos of Tempest. If an avenue is blocked to me via an adversary, that's not a problem. I've got other avenues to get around that."

Breakthrough capabilities

Smith is, understandably, coy about discussing some of the cutting-edge and highly classified sensor and avionics capabilities that will be included in Tempest, whether it is how many Gb/Tb of data might be collected per second, the balance between on-board/off-board processing, whether distributed apertures/antennas might enable the computers to 'stitch' together AESA radars for a 360° spherical view, or how the platform might not just be a 'user' of space information (such as satellite imagery piped directly to the cockpit) but also might contribute to the 'Space Cloud' itself [see *Superiority through space*, p38].

One analogy from Leonardo is that Tempest will be able to 'suck up' the equivalent of a medium-sized city's worth of data in one second. It will also be able to share this unparalleled information to other users: "The days of a selfish fighter aircraft when we talk about Tempest are gone."

However, Smith was able to reveal that each individual technology building block going into GCAP's ISANKE represents a major breakthrough itself. "The important thing to know is there are individual groundbreaking technological advances being made in all of those sensing areas that we are talking about but then they're all being harnessed together again, in a paradigm shifting sixth-generation capability to multiply those advantages that you're getting in those technological leaps."

Given the heavy reliance on software – what about the hardware, especially computers which might be outdated in the commercial world the moment that an aircraft's first metal is cut? Says Smith: "All aircraft will hit that upgradability wall, eventually, no matter how good it is." However, he explains: "Another design



ethos behind Tempest is rapid upgradability which has been designed in from the start. Clearly it will hit a buffer at some point but it's about pushing the horizon of that buffer further out, substantially further than any in-service platform. This will future-proof the UK and our partners beyond the limits of existing aircraft."

It also needs to be remembered that, while Leonardo UK is bringing its formidable experience, skills and knowledge in radars, sensors and EW as part of the UK Team Tempest consortium, it is working closely with industrial partners in Italy (Leonardo and ELT Group) and Japan (Mitsubishi Electric) as part of the trinational GCAP effort, merging the best of the three nations' expertise in combat aircraft electronics, sensors and software. "It's not about filling gaps between partners; we are collaboratively working to make the whole greater than the sum of its parts and realise synergies."

Summary

Thus, while much of the radar, sensor and EW systems that will go into Tempest/GCAP still remain secret, it is clear that the goal is a step change over current fifth-generation platforms and to leverage advances in AI, machine learning and sensors that elsewhere in the world are proceeding at breakneck pace. Says Smith: "Tempest will have an advantage over legacy aeroplanes because of the breadth of sensing



and the integrated nature. It will allow the platform and the operator to perform those multiple tasks simultaneously and, to achieve those multiple missions simultaneously in a way that neither the F-22 or the F-35 can deliver. It has been designed from the very start with that ethos built into it."

He also stresses that, despite the reliance on software, deeply integrated sensor and communications' capabilities are not things that can be retrofitted easily to older platforms. "The Lockheed Martin mantra, which is absolutely true, that you can't make a truly stealthy aeroplane out of an aeroplane that wasn't stealthy to start with also applies to this. It has to be designed in from the start and the same philosophy absolutely applies to this simultaneous mission and integrated sensing capability."

Created from the outset to survive and dominate in the battlespace of tomorrow, Tempest then could be considered to be designed from the inside out.

All images: Leonardo UK

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Future combat air: *Superiority through space*

Space is a key segment that will underpin future combat air systems, especially when it comes to having the upper hand in information and intelligence. **BELLA RICHARDS** looks at how Airbus plans to connect air and space combat clouds in the FCAS programme.



If you want to have air dominance, you cannot do it without space. As nations across the globe dig deeper into developing their sixth-generation fighter programmes, it is clear that space is increasingly being recognised as a vital segment of air combat systems and must be utilised, especially for information warfare. Now, more than ever before, space will be integrated into the ecosystem of future fighter programmes, due to the huge benefits Earth's orbit can provide – whether securing high data communication, accessing near real-time connectivity, or delivering space-based sensors that can exploit satellite constellations to detect hypersonic or stealth platforms efficiently.

While space will likely be part of each of the programmes currently under way across Europe, the Future Combat Air System (FCAS) – involving France, Spain and Germany, which will replace existing aircraft, such as the Eurofighter or the Typhoon – seems to be spearheading the involvement of space through Airbus' Multi-Domain Combat Cloud.

A snapshot of the Combat Cloud

The cornerstone of connecting the Next Generation Weapon System (NGWS), incorporating both piloted fighters and uncrewed remote carriers, will be the

▲ The multi-layered satellite system will connect to the fighter jet, the uncrewed remote carriers and the other assets across land, sea and cyberspace to provide information intelligence.

Multi-Domain Combat Cloud (the 'Combat Cloud'). This 'system of systems' will connect all elements of FCAS across land, air, sea, cyber and space to ensure seamless information sharing and intelligence with all platforms. "There is no air dominance without C5ISR [Command, Control, Computers, Communications, Cyber, Intelligence, Surveillance and Reconnaissance] dominance, and this is why space is integral to FCAS," Airbus Defence and Space told *AEROSPACE*. "In increasingly denied environments, space will provide connectivity, navigation and timing aids and real-time situational awareness to support operational commanders at all levels."

The Combat Cloud, loosely resembling the 'Cloud' systems used by Google and others, will integrate legacy platforms, such as existing satellite constellations, like Galileo or GPS, to provide real-time navigation and timing to jet fighters and other assets. However, Airbus Defence and Space explained that, because satellites typically have a lifespan of up to 15 years, there will be new infrastructure built in 2040 and beyond to replace current constellations, and connectivity will be "delivered by a multi-layered architecture mixing GEO [Geostationary Orbit] and MEO/LEO [Medium/Low-Earth Orbit] assets and connected through inter-satellite links."

Developing a multi-layered system offers many advantages, such as the need for an increase in capacity to accommodate greater amounts of data, more flexibility to serve traffic distribution in hotspots, and better security to steer clear of interference from red forces and remaining resilient amid potential system failures (such as the loss of a satellite).

From space to the cockpit

How will this system work in the cockpit? Paramount to the effectiveness of next-generation fighters and remote adjuncts will be their ability to be equipped with satellite communication capabilities, which Airbus believes is possible, due to the technological advancement of the flat antenna. The data collected from these satellites will be accessible in the aircraft through both optical and radio frequency (RF) links. This data will be distributed within the Combat Cloud,

giving the pilot real-time information about the situation, no matter where the jet is geographically. “We are working on new designs for the cockpit, including the usage of artificial intelligence (AI), which will help the pilot make relevant decisions faster,” Airbus said.

These new innovations are particularly relevant, due to the fact that current fighters are more restricted when it comes to adapting to rapidly changing situations. Airbus describes current fighters as having “very limited connectivity,” due to mission plans being defined and uploaded before the flight and, therefore, giving little room for alterations as situations change. “Today it is quite challenging to replan the mission during the flight but tomorrow the pilot will be a mission commander. He/she will rather focus on commanding a mission with their remote carriers rather than focusing on manoeuvring the aircraft,” the manufacturer described. Furthermore, pilots will be directly involved with the battle management process, thanks to the higher levels of intelligence they receive from space.

Far from smooth sailing

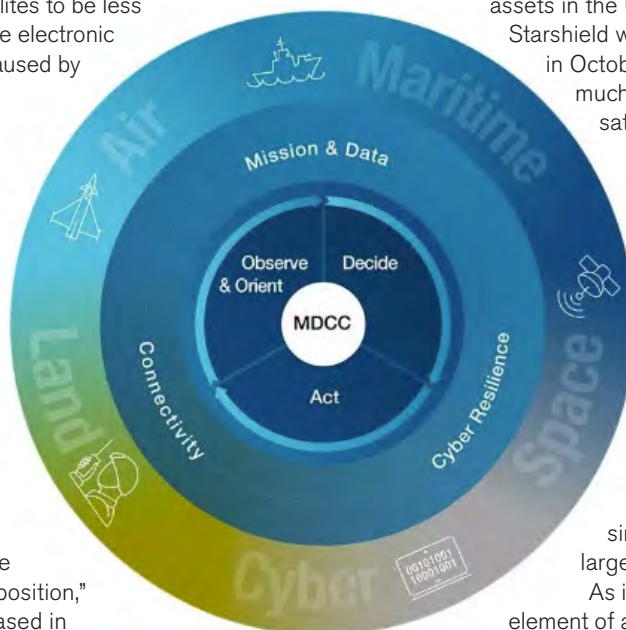
With space needing to connect with the air domain for the first time on such a large scale, there are inevitably several hurdles to overcome. One of the primary challenges is the potential for jamming, a familiar threat to all defence environments. One way to ensure satellite resilience with the Combat Cloud will be the adoption of optical communications between aircraft and satellites to provide “non-jammable high data rate capacity to the forces,” Airbus told *AEROSPACE*. Optical communications are built with a tighter, more precise laser beam than RF, therefore making data more secure and harder to interfere with. Furthermore, Airbus will protect its infrastructure by hardening its satellites to be less sensitive to jamming and making the electronic systems resistant to interference caused by harsh radiation.

Secondary to resisting the threats of jamming are some of the practical challenges, such as ensuring satellites can easily connect to aircraft flying at extremely high speeds and performing advanced manoeuvring. “To avoid disconnections during flight, laser communication terminals, such as those from Airbus Defence and Space’s Tesat subsidiary, feature a hyper-hemispherical field-of-regard so that the lens can follow its target while moving at high speed and the satellite doesn’t have to adjust its position,” Airbus told *AEROSPACE*. Tesat, based in

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IN AN INCREASINGLY DENIED ENVIRONMENT, SPACE WILL PROVIDE CONNECTIVITY, NAVIGATION AND TIMING AIDS AND REAL-TIME SITUATIONAL AWARENESS TO SUPPORT OPERATIONAL COMMANDERS AT ALL LEVELS

▼ A visual diagram showing the full scope of how the Combat Cloud will inform decision-making and deliver important intelligence to land, air, sea and cyberspace.



Germany, provides several services and products for the aerospace industry, such as laser terminals, telecommunications and telemetry solutions.

Progress so far

Airbus is confident it will deliver the Combat Cloud by 2040, the timeline by which FCAS is expected to be operational. Currently, the programme is in Phase 1B, which is focused on defining the final architecture of the system, including the fighter and the type of remote carrier vehicles that will work hand in hand with the jet. By the end of Phase 2, Airbus hopes to have delivered a Combat Cloud demonstrator and have performed a flight demonstration with the system. The company will soon begin testing its TELEO optical communications demonstrator, which was launched into space in May last year from Florida, on board the Arabsat Badr-8 telecommunications satellite. The TELEO payload will facilitate extremely high-capacity optical feeder links between GEO and ground infrastructure to enable huge data transfer, which will greatly benefit the Combat Cloud’s ability to process information.

Space superiority

Space will soon form part of the information warfare blueprint across the globe. In January, the US Air Combat Command even announced that the 16th Air Force will integrate space into all warfighting functions, specifically information warfare, signifying a broader movement towards space being identified as key in air defence.

Meanwhile, SpaceX’s Starshield, a future military version of the company’s Starlink satellites, will likely provide communication links to defence assets in the US, potentially with fighter jets. While Starshield won a \$70m Space Force contract in October 2023, SpaceX is yet to disclose much more about what applications the satellites will serve.

While the Combat Cloud is being developed under the French, Spanish and German FCAS programme, Airbus has made it clear that the system should be interoperable with various other programmes, such as GCAP or NGAD, but insists that there must be a stronger alignment on common standards of communication and data with other allies. However, it is unknown whether other future air combat programmes will adopt similar measures that utilise space on a large scale.

As it stands, space should become a core element of all future fighter programmes.

Advertorial

From Vision Through Velocity... Transitioning Technology into Reality

By Russell Boyce, AIAA Aeronautics Domain Lead



In the pursuit of a sustainable and high-tech future, researchers, engineers and pioneers are driving innovation in aviation. 2024 will be a landmark year with the first certification of electric VTOL aircraft, flight testing of new supersonic vehicles, expanded use of automated or autonomous systems and continued progress of military programmes. As aviation accelerates, innovators are bridging the gap between visionary concepts and tangible technological reality every day.

However... the world is facing rapidly evolving generational-scale challenges – societal, economic, environmental, security – alongside those rapidly evolving technical capabilities. How do we achieve net zero greenhouse gas emissions by 2050 while simultaneously advancing multimodal mobility solutions that take the world forward? What could a disruptive “AI-in-the-DNA” future look like for the world and for the mobility solutions we will trust? What does a future highly skilled workforce look like, how will they be different from today and how will they have been educated and trained?

The aerospace sector cannot and does not exist in isolation from such challenge nor from the broad landscape – or ecosystem – of policy, technology, investment, business, government, and end-user stakeholders grappling with them. Our community is brilliant at technology but that's

not enough. It is critical that we embrace system-of-systems thinking, building understanding and collaboration across the ecosystem of stakeholders, so that the technological innovations we have no difficulty in creating are financeable, certifiable, publicly acceptable and driven by and tuned for the challenges.

Over the coming decade, we will see many new aeronautics capabilities introduced. The next generation will experience flight in ways we are just imagining. AIAA is excited about advancing these opportunities as we move from vision through velocity, transitioning technology into reality. AIAA is even more excited about the ways that will unfold as partnerships with non-aerospace stakeholders to address global needs.

To join this timely conversation, plan to attend the 2024 AIAA AVIATION Forum, 29 July–2 August 2024, in Las Vegas, Nevada. Thought leaders from across the ecosystem will share, discuss and debate the opportunities and challenges. New advances in aviation will be unveiled across a vast technical programme. The conversation will flow from the big picture view from 50,000 feet, through developments poised to shift the transportation paradigm, to addressing global challenges, embracing transformational technologies both from within and from without (there's blue sky over the horizon), and finally asking “where to from here?”

We cannot predict the entire future of aviation but the AIAA community is set to lead its shaping. Visit aiaa.org/aviation for more information.

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● DEFENCE

International fighter programmes



Fight club

Setting aside GCAP, FCAS/SCAF and NGAD, there are at least eight future fighter types taking shape elsewhere in the world – at least three of which have already flown. **JOE COLES** and **JIM SMITH** take a look at these programmes.

Not since the 1960s have so many advanced combat aircraft been in parallel early development. Outside the Western sphere of influence, eight national combat aircraft are taking shape. These are fighters with a strike capability, which have similar characteristics to the US F-22 and F-35 and, while the properties of these aircraft vary, the common intent is to provide air defence and strike capabilities in a networked, supersonic, multirole platform while having a reduced radar signature.

Why develop rather than buy?

Why are these nations embarking on what will, for all participants, be a lengthy, expensive and risky enterprise? Long development times are characteristic of major air combat programmes, particularly where participants are relatively new to the field or have not previously worked with other partners. Costs will generally be higher than buying a ready-made product and are often underestimated at the start of a complex project, especially if locally designed and manufactured weapons, sensors and systems are to be incorporated.

With all these negatives, offshore sourcing may seem to be the logical path. However, for many, nation sovereignty and independence is important. There may be a strong desire to ensure that major elements of the nation's defence remain under national control and that third-party constraints cannot be imposed on their operation or their industrial exploitation through sales or technology adoption. Nowhere, perhaps,

is this motivation more evident than in Türkiye's development of the TAI Kaan. Türkiye had positioned its industrial base to contribute significantly to the F-35 programme, with the expectation that this would become a key component of Türkiye's air combat capability. However, the decision to procure the Russian S-400 surface-to-air missile for its ground-based air defence system has resulted in Türkiye being barred from the F-35.

India has been pursuing a course of 'Indianisation' of its aerospace capabilities for many years, with parallel projects developing design and manufacturing skills on progressively more complex programmes, while also gaining experience and capability in licence construction, system integration and upgrades to products designed overseas.

The recent entry into service of the Tejas aircraft is one element of this programme but India's system development capabilities are also evident in a wide variety of weapons, sensors and system integration efforts. In the long term, this grand endeavour seems to be driven as much by a desire for independent control of defence technologies as by the desire for industrial independence and innovation with the long-term aim being to avoid dependence on Western and Russian systems.

The South Korean position is different. South Korea has a strong alliance with the US and will be operating the Lockheed Martin F-35A as a key element of its air combat capability. However, like India and Türkiye, South Korea has been building its aerospace industrial capabilities with a range of

▲ South Korea's KF-21 will be available for the export market. The aircraft first flew in July 2022.

Global fighter specifications

Data (best data as available)	Kaan	KF-21	TEDBF	AMCA	Su-75	FC-31
Span (m)	14.0	11.2	11.6	11.1	11.5	11.5
Length (m)	20.5	16.9	16.9	17.6	17.3	17.3
Height (m)	6.0	4.7	4.7	4.5	4.7	4.8
Wing Area (m ²)	70.0	46.5	56.1	55.0	55.2	55.0
Aspect Ratio	2.8	2.69	2.4	2.24	2.27	2.64
Propulsion	2 x F110	2 x F414	2 x F414	2 x F414	1 x Saturn AL-51	2 x WS 19
Max Thrust in A/B (kN)	2 x 131	2 x 97.9	2 x 97.9	2 x 97.9	171.7	2 x 117.7
Empty Weight (t)	17.0	11.0	14.0	12.0		
Gross Weight (t)	27.2	18.5	23.5	20.0		
Internal Fuel (t)	8.0	6.0	8.0	6.5		
Combat Weight (t)	23.2	15.5	19.5	16.75	17.0	20.0
Max Mach No	1.8	1.8	1.6	2.15	1.8	1.8
g limits	+9/-3.5		+8/-3		+8	
Weapons Bay	Y	Provision	N	Y	Y	Y
Thrust Vectoring	N	N	N	N	Y	?
Combat Thrust/Weight	1.15	1.28	1.02	1.19	1.0	1.2
Wing Loading (kg/m ²)	331.4	333.3	347.8	304.5	282	363.0
Signature	Reduced	< Gen 4	< Gen 4	Reduced	Reduced	Reduced

products, including autonomous systems, helicopters and the KA-50 light fighter. The KF-21 provides an opportunity to increase the combat power of the Republic of Korea Air Force (ROKAF) using a locally manufactured and supported adjunct to the F-35 in an environment where the longer-term intentions of North Korea remain uncertain.

Russia and China are, of course, global powers with large armed forces and demonstrated technical capability across the aerospace, weapons and sensors' spectrum. The two projects considered here are somewhat enigmatic and, after considerable initial publicity, have faded from the public eye in recent times.

South Korea

The KAI KF-21 Boramae ('Fighting Hawk') is currently being developed by South Korea with Indonesia as a key partner. The prototype was rolled out in 2021 and made its first flight in July 2022. There are currently four aircraft in flight testing, one of which is a two-seater. The KF-21 is currently designed to carry its stores externally but space and volume provisions have been made in the fuselage for the future incorporation of internal weapons bays. This results in the flattened trapezoidal shape of the fuselage which is typical of fifth-generation projects. The current aircraft has ten external hardpoints, facilitating the carriage of a variety of air-to-air and air-to-surface weapons.

The KF-21 has adopted the approach of seeking performance comparable to Gen 4 platforms, such as Typhoon and Rafale but with a lower radar signature. The available data suggests the KF-21 is a significantly smaller aircraft than the other aircraft considered here, perhaps indicating a relatively small internal fuel volume. Taken together with the low empty weight, the figures suggest that the aircraft is primarily intended as an air defence interceptor, rather than for air superiority, and this is not entirely surprising, given the geographic and political position in which South Korea finds itself.

As an interceptor, the KF-21 seems optimised with a high climb rate and good manoeuvre performance, thanks to its high thrust-to-weight ratio. The initial development has been aimed at producing a flexible, high-performance aircraft with the option of moving towards an LO platform in the future. This strategy may have been adopted to minimise risk and shorten the initial development time.

South Korea intends to operate the KF-21 alongside the F-35 and will face interesting decisions as development proceeds. One option will be to implement the internal carriage of stores, thus reducing its radar signature and positioning the KF-21 as a strike or fighter adjunct to the F-35. A development programme to realise this capability could be quite challenging, given the degree of detailed attention required to minimise the signature of an existing design.

Alternatively, external store carriage could be continued with the internal volume available being used to increase fuel, offering the option of using the KF-21 for defensive air patrols or as a flexible strike asset.

“As an interceptor, the KF-21 seems optimised with a high climb rate and good manoeuvre performance, thanks to its high thrust-to-weight ratio”



South Korea's KF-21 KAI

● DEFENCE

International fighter programmes

Türkiye

The TAI Kaan is a twin-engine, twin-fin design, with a passing resemblance to the US F-22. This likeness is enhanced by the flattened trapezoidal cross-section of the fuselage which is a common feature of nearly all current new-generation projects.

The Kaan is the largest and heaviest of the future fighter aircraft currently in development. Bearing in mind the relatively large size of Türkiye and that the plan to interoperate the aircraft with the F-35 has had to be shelved, this suggests that Kaans are expected to deliver greater endurance and range than the other concepts.

The lower fuselage features a large weapons bay to enable the carriage of a wide variety of mainly, but not exclusively, indigenous-developed weapons. This would be consistent with the design being expected to operate in both air defence and penetrating strike roles.

ROKETSAN, the main weapons contractor in Türkiye, is working on a version of its SOM cruise missile that is suitable for use by the F-35. Elsewhere, TÜBİTAK SAGE is working on the GÖKTUĞ family of air-to-air missiles, Bozdoğan is analogous to the AIM-9X, Gökdoğan to the AIM-120 and Gökhan to the Meteor. Air-launched weapon systems are one of the most mature areas of the Turkish defence sector.

In the accompanying table we have estimated the combat weight of the aircraft (defined as the weight of the aircraft in an air combat configuration with 50% internal fuel), its thrust-to-weight ratio and the wing loading of the aircraft at that combat weight. These figures suggest that the platform point performance is perhaps more focused on Beyond Visual Range (BVR) air defence and less on Within Visual Range (WVR) turning air combat. This may change if higher thrust engines are fitted to the production aircraft or if thrust vectoring is introduced.

While efforts have been made to avoid unnecessary radar signature, more is required to achieve VLO which will be essential if the aircraft is to operate as a BVR fighter and strike aircraft.

At this stage, the Kaan appears not to achieve the VLO characteristics of recent US designs but Türkiye could incorporate the necessary coatings, treatments and devices to significantly reduce the observability of future aircraft. These would need to be incorporated in the design and manufacture of production aircraft but, at this point, the prototype shows no evidence of this – one would expect to see a gold-flashed cockpit, treatment of edges and panel junctions, for example. It should, however, be noted that Türkiye's indigenous capability for composite materials' production is widely respected.

Given the history outlined above, the primary aim for Türkiye could have been to replace the F-35, now that is no longer available. The move by the US to bar the acquisition of the F-35 seems to have broadened the scope of the project to include providing greater air-to-air and air-to-surface weapons capability, with a larger weapons bay and generally greater store carriage capability.

Further development is likely to be seen in the development of a locally-produced powerplant for the aircraft; realising the LO potential of the airframe; incorporation of the on-board systems and sensors required to detect, localise and attack air and surface targets; and the integration of the necessary weapons and links to off-board systems, including co-operative uncrewed combat systems. Aselsan will be the contractor for the sensor suite and avionics of the aircraft, including an AESA radar. Arguably, the biggest question for Kaan is how far LO will be achieved.

“Air-launched weapon systems are one of the most mature areas of the Turkish defence sector”



The TAI Kaan

India

These are two Indian projects which intend to produce next-generation replacements for the Indian Navy's MiG-29K and the Indian Air Force's Su-30MKI.

The general requirements for a carrier-based combat aircraft are to protect the carrier battle group against air attack, to counter threat surface combatants and to project power by striking land targets from offshore. It is desirable to do this with one platform, if possible, mainly because of the space and logistical difficulties introduced by using separate strike and air defence aircraft. These requirements may be quite problematic for nations unable to afford the US supercarrier approach. Air defence is likely to require stand-off patrols to counter anti-ship missile launch aircraft and adequate performance to defeat fighters. As a result, the requirements for performance, manoeuvrability, range and endurance are likely to be quite demanding. Meanwhile, attacking threats on the surface is likely to require the carriage of relatively large weapons, both to achieve sufficient stand-off distance and effectiveness. This mix of demanding requirements, coupled with the additional weight required to fold wings, to recover via no-flare arrested landings, and the desire to have a low signature, is a difficult problem.

“The sceptical observer may look at the progress and issues with the Tejas light fighter programme and wonder if Indian industry has bitten off more than it can chew with these future fighters”

From an Air Force perspective, the job of off-shore fleet air defence can safely be left to the Navy and countering surface combatants can be achieved, if required, by the use of non-fighter platforms (such as large cruise missiles launched from aircraft, like the Tu-142) or, in the future, by stand-off missiles launched from maritime patrol aircraft.

This approach results in an Air Force emphasis on internally carried anti-air and strike weapons, along with supporting systems, like AEW&C, air-to-air refuelling, surveillance and reconnaissance, communications and data links.

From this brief and somewhat superficial analysis, we can see that requirements for next-generation Naval and Air Force combat aircraft may result in quite different solutions. Furthermore, there may have to be some compromise in the requirements for a multirole low signature Naval solution.

Looking at the Twin-Engine Deck-Based Fighter (TEDBF), the first impression of the design is that the wing, canard and fin of the Typhoon have been grafted onto the fuselage of the Rafale, with the addition of fuselage shaping, diverterless intakes and some edge alignment to

reduce the signature of the clean aircraft. The requirement compromise that has been made is the external carriage of stores. In essence, the aircraft could, perhaps mischievously, be described as an Indianised Rafale.

At this relatively early stage in its development, the Advanced Medium Combat Aircraft (AMCA) is, in many ways, similar to the Korean KF-21, albeit slightly larger. The relatively small size and internal fuel volume is a surprise, given the stated intent to replace the Su-30 MKI, an aircraft which has an empty weight about 50% greater than that stated for the AMCA. That said, very little reliable data on the AMCA is available and it would not be surprising to see some growth in the weight of the aircraft, along with a corresponding reduction in the claimed performance as development proceeds. Both aircraft are likely to migrate to a suitable Indian-designed and manufactured engine once one is available and will also rely heavily on Indian-produced sensors, systems and weapons.

The sceptical observer may look at the progress and issues with the Tejas light fighter programme and wonder if Indian industry has bitten off more than it can chew with these future fighters. The scale of India's military aerospace industry's ambition is vast and is working in every conceivable category. Whether both can be developed simultaneously, and if TEDBF offers a sufficient increase in capability over existing systems to merit the effort, remain valid questions. Time will tell if the AMCA and TEDBF are cases of ambition over practicality.



Model of the the Twin-Engine Deck-Based Fighter (TEDBF)



Model of the Advanced Medium Combat Aircraft (AMCA)

● DEFENCE

International fighter programmes

Russia

Russia's enigmatic Sukhoi Su-75 Checkmate was initially announced as a private-venture export fighter and is believed to be continuing, despite the absence of any likely customers as Russia is plunged into both a war footing and international pariah status.

Sukhoi is hoping for orders for the Su-75 once Russia regenerates and modernises its Aerospace Forces (VKS) after the Ukraine conflict is resolved. While the future direction of the project is currently unclear, it is claimed to be continuing towards the construction and testing of prototypes, optimistically predicted to occur in 2024 (though they may not be flying prototypes). Russian companies have made patently untrue claims of their products, both in terms of performance and schedule in the past so any claims must be held in this context.

The configuration of the Su-75 differs markedly from the others considered here, having a single engine, thrust vectoring and twin fins (in some ways resembling some of the Western ASTOVL and JAST studies of the late 20th Century). The wing is a straked delta with large triangular control surfaces recently added at the trailing edge of the wing and no tailplane. The forward fuselage features a wrap-around diverterless intake, and three weapons bays are incorporated, one in the centre and two side-mounted bays. More recent configuration changes have reduced commonality with the Su-57 but they are still planned to share many systems, including a simplified NIIP N036 Berka AESA radar and L-band 'anti-stealth' radar arrays in the leading edges of the wing. The thrust-to-weight ratio is stated to be 1.0, although the aircraft load-out is not stated. If this is at a combat weight it is certainly not impressive. Overall, the configuration suggests that the sustained turn rate will be relatively modest, due to the low aspect ratio and the relatively low thrust-to-weight ratio, but the instantaneous turn rate will be assisted by thrust vectoring and vortex lift from the leading-edge strakes.

The critical questions for the Su-75 are clearly whether a customer can be found and, if volume production is to be assured, whether the aircraft has a place in the VKS. Considering the VKS' urgent need for aircraft right now, and its preference for the Flanker series, the Checkmate appears an unlikely project (the Su-57 appears an unnecessary luxury to the VKS). Reports of the long-rumoured ultra-fast replacement for the MiG-31 seem to have dried up and little has been heard of late of either Mikoyan's fifth-generation carrier fighter (a canard delta reminiscent of the Mikoyan Project 1.44) or its light multirole aircraft (similar to the KAI T-50 in class and configuration).

“The critical questions for the Su-75 are clearly whether a customer can be found and, if volume production is to be assured, whether the aircraft has a place in the VKS”



Sukhoi Su-75 Checkmate

China

The Shenyang FC-31 first appeared in public in 2012. In appearance, the aircraft is reminiscent of a slightly smaller F-22, with twin engines, twin outward-canted fins and twin diverterless intakes on the side of the fuselage. Very little firm data is available about the aircraft and the limited figures in the data table are rough estimates. The aircraft was developed as a private venture, aimed at an export market as an alternative aircraft for those nations unable to buy the F-35. One of the initial customers is Pakistan, and China's PLA Navy air arm is also likely to acquire the aircraft, a possibility strengthened by the appearance of a navalised variant of the aircraft with folding wings and a catapult-compatible undercarriage in October 2021.

Were the PLA Navy to acquire the FC-31 for its aircraft carriers, China may be able to use air-launched, anti-ship missiles to deter surface combatants in much of its potential area of operational interest. Outside this area, anti-ship missiles could still be carried externally if necessary. Little is certain about China's next-generation fighter, though several Chinese manufacturers have revealed models and research material relating to a tailless flying wing design, sharing much with artworks representing the US NGAD in the public domain. The elimination of vertical control surfaces on fighter aircraft has long been desired, as it is necessary for the highest degree of LO but has yet to be applied to operational fighters.

“One of the initial customers is Pakistan, and China's PLA Navy air arm is also likely to acquire the aircraft”



Shenyang FC-31



Shenyang FC-31

Afterburner

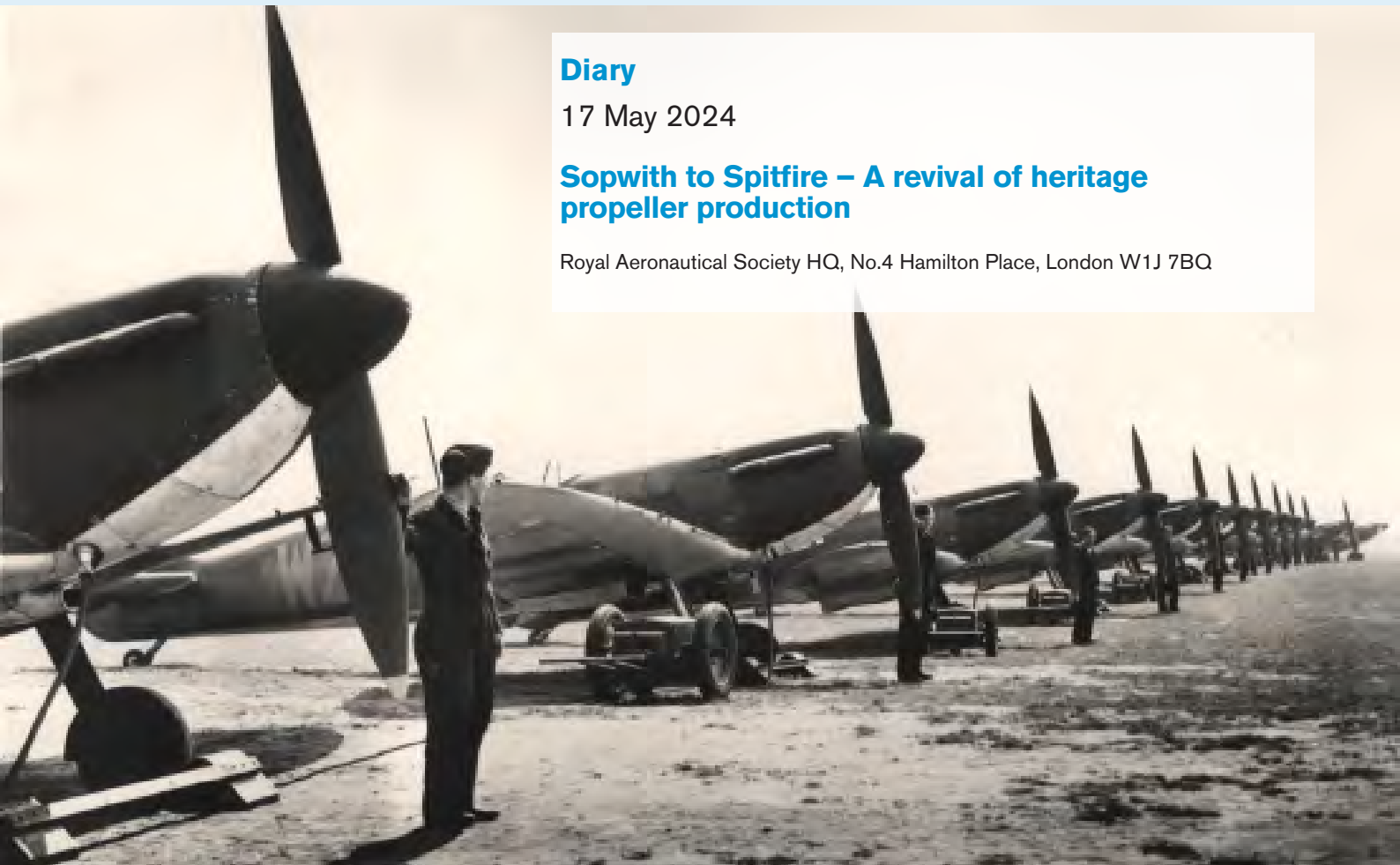
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Diary

17 May 2024

Sopwith to Spitfire – A revival of heritage propeller production

Royal Aeronautical Society HQ, No.4 Hamilton Place, London W1J 7BQ



A line-up of 19 Squadron Supermarine Spitfires at RAF Duxford before the outbreak of WW2. This is one of the first images released of the Spitfire in squadron service.

NAL/RAeS

48 Message from RAeS

– From the President

"Being your President has been an immense privilege and meeting so many of you over the past year has reminded me what a small world we live in, one that is forged through personal connections made possible by the wonder of flight."

– From the Chief Executive Officer

"Once again, the meeting highlighted the challenges we have in recruiting and retaining aircraft engineers and it remains a strong focus for the Society as we work with a number of other charities and businesses on practical solutions to address these concerns."

50 Life in the Hornets' nest

On 17 January, retired airline captain, Nick Anderson returned to the Weybridge Branch to recount the next chapter in his 19-year military career after last year's highly popular 'Chasing Bears in a Phantom' talk.

52 RAeS President releases 'Future of Flight' paper

Brought together by outgoing RAeS President 2023-24 Kerissa Khan, a group of global experts has contributed to an innovative 'future gazing' RAeS discussion paper, called 'Shaping the future of Advanced Air Mobility Safety.'

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Message from RAeS

OUR PRESIDENT

Kerissa Khan



“

IT WAS INCREDIBLY REWARDING TO HOST A SPECIAL PRESIDENT'S COOL AERONAUTICS EVENT...THE SQUEALS OF EXCITEMENT ECHOING THROUGHOUT OUR HQ AND THE GRATITUDE OF THE STUDENTS, PARENTS AND TEACHERS WILL REMAIN A FAVOURITE MEMORY

► RAeS President Kerissa Khan with school children at the Cool Aeronautics event in September 2023.
Tim Robinson/RAeS

It has been an extraordinary honour to serve as your President for the past year. As my tenure draws to a close, I am immensely proud and pleased to share some of the progress we have achieved together in this exceptional and transformational year.

I dedicated my presidency to 'Pioneering Future Flight Innovation', focusing on three key areas:

- Inspiring today's and tomorrow's pioneers of flight
- Integrating new emerging players in future flight innovation into our wider community and,
- Strengthening and showcasing the Society's relevance in this new and exciting era

Using my distinctive platform as the youngest, first ethnic minority and second woman appointed as President, I shared my career journey and engaged with students around the world to inspire the next generation of pioneers of flight. With STEM outreach, the Society has empowered thousands of young people worldwide to pursue careers in aerospace, aviation and space – through initiatives like Cool Aeronautics and Project Altitude reaching young people from low-income and rural areas, participation in STEM fairs and our annual Careers in Aviation and Aerospace event.

This includes our inclusive Falcon 2 programme, of which I am especially proud of, which worked with more than 200 children to design a flight simulator for those with special educational needs and disabilities (SEND).

It was also incredibly rewarding to host a special President's Cool Aeronautics event, specifically for children from lower socio-economic backgrounds. The squeals of excitement echoing throughout our HQ and the gratitude of the students, parents and teachers will remain a favourite memory.

We welcomed more than 2,900 new student members, launched a new series of social AerosocietyLate events, including a quiz, film and games night, and established the first ever President's Young Pioneer Award.

Membership has also grown substantially and I was delighted to award 300 new Fellows and welcome more than 3,700 new members during my tenure.

In September, the President's Future of Flight Summit played a key role in stimulating discussion

around advanced air mobility, sustainable aviation, electric propulsion and autonomous aircraft. We additionally delivered more than 400 lectures, briefings and conferences, totalling over 10,000 hours over the past year.

Through international engagements, including presidential visits to the Paris, Dubai and Singapore airshows, we reinforced existing and established new partnerships with members, Corporate Partners and supporters across the globe. Connecting with approximately 70 companies whilst overseas, we enhanced our diverse portfolio of Corporate Partnerships.

Contributing to shaping the 2024 Davos agenda has been a major highlight for me, fortifying the Society's relevance in influencing international policy at the World Economic Forum. Other highlights include delivering keynote addresses to government ministers, regulators, industry, academia and defence leaders across the UK, France, Germany, Netherlands, UAE and Singapore. Signing the UK Defence Aviation Net Zero Charter at RIAT, I showcased the Society's important role in championing net zero targets.

My final contribution will be the publication of my President's briefing paper on Future of Flight Safety, shaped with an international expert panel (see p52). This adds to other thought leadership learned papers on contrail management, mental health and ATM published over the past year.

I would like to congratulate David Chinn on his appointment as the next President and extend my gratitude to Dave Edwards, Council, the entire remarkable HQ team, our members and volunteers. Your loyal support has been invaluable in delivering a successful year with a lasting impact.

I strongly encourage you to build on the progress we have made collectively as a global community during this transformational year. With shifting environmental, socio-economic and geopolitical challenges, the RAeS remains pivotal in securing a sustainable, resilient and equitable future for our sectors.

Being your President has been an immense privilege and meeting so many of you over the past year has reminded me of the small world we live in, one that is forged through personal connections made possible by the wonder of flight.



OUR CHIEF EXECUTIVE OFFICER

David Edwards



As I write this on a flight home from a long weekend in the US, it has been pleasing to see that every flight has been packed and that airline travel has returned in force. I was lucky enough to get some time on the *USS Intrepid*, a 1943 aircraft carrier-turned-museum moored up on Pier 86 in Manhattan. If you're ever in New York, try and make some time for it, because it's also the final home of one of the British Airways Concorde's (G-BOAD) and the Space Shuttle *Enterprise*, covering all the areas of our Society.

On board Concorde, battered by the April winds adding a sense of motion to the parked-up aircraft, it was amazing to hear the questions being asked by young and old about this historic airliner and what it did. While it is starting to look its age inside, the fresh coat of paint on the outside makes it look as current today as ever. The lack of engines probably won't help a comeback though, sadly.

I know that Concorde was one of the main inspirations for our departing President, Kerissa Khan. She has had an incredible Presidential year, which has attracted a great deal of attention to us and to our work, from being at the World Economic Forum to representing the Society at a large number of events across the UK and Europe, through to chairing Council and using that forum to ask significant questions to your representatives about the future of aerospace, aviation, space and the Society itself. It has been a great year and I sincerely thank Kerissa for everything she did on your behalf and, I have no doubt, we'll continue to see her as a strong part of the Society's journey in the future.

As I said last year, this is the season of change for the Society, and as Kerissa departs to become our past President, we welcome David Chinn FRAeS to the role of President. David has been a very active member of the Society for many years and has served on Council and the Trustee board in the past. It's clear that this is going to be a year continuing the theme of inspiring the next generation – particularly when it comes to getting young people to fly – so I'm very much looking forward to it!

We also say goodbye to a number of our Council members who are stepping down after serving the Society, and we will shortly be welcoming our newly

elected representatives. I was particularly delighted to see so many nominations for Council this year – even if you haven't been successful this time, thank you for putting yourselves forward and, to everyone, we're always looking for new volunteers to sit on all of our Boards and Committees which help the Society deliver our aims so please do keep an eye open for those opportunities as they arise.

It's been another busy month around the rest of the Society. We were very lucky to have a Corporate Partner briefing from Air Chief Marshal Sir Richard Knighton, the Chief of the Air Staff, interviewed by Sir Chris Harper, on today's capabilities and threats. The recording of the session will be made available as a podcast, though the attendees were also treated to a Chatham House Q&A session which was very well received. We were delighted to host Sir Richard just ahead of our Future Combat Air and Space Capabilities Summit this month, and which this issue is themed around.

I was very fortunate to be invited by Geoff Winterbottom FRAeS, a Council member, to visit RAF Brize Norton and to view the work of Air Tanker, the Civil/Military operation providing air-to-air refuelling and transport operations. Once again, the meeting highlighted the challenges we have in recruiting and retaining aircraft engineers and it remains a strong focus for the Society as we work with a number of other charities and businesses on practical solutions to address these concerns.

We were delighted to welcome a delegation from the US Congress' Transportation Committee where they also met with representatives from the CAA and FAA. I had some time to explain to them the importance of the Society to the sector and our role over many years in those transatlantic discussions.

You still have a short time to buy tickets for the Society's Annual Banquet, taking place on 16 May at the Intercontinental Hotel in London. It is one of the significant events in the Society's calendar, bringing together a wide range of attendees from across our broad sectors and with very special guests. This year we'll be honoured to hear from Stacy Cummings, our guest of honour, who heads the Support and Procurement Agency at NATO, an incredibly important role in the present climate.

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ONCE AGAIN,
THE MEETING
HIGHLIGHTED
THE
CHALLENGES
WE HAVE IN
RECRUITING
AND RETAINING
AIRCRAFT
ENGINEERS
AND IT
REMAINS
A STRONG
FOCUS FOR THE
SOCIETY

Society Events

LIFE IN THE HORNETS' NEST

On 17 January, retired airline captain, Nick Anderson returned to the Weybridge Branch to recount the next chapter in his 19-year military career after last year's highly popular 'Chasing Bears in a Phantom' talk.

This time it was about his exchange posting to the Royal Australian Air Force (RAAF) to fly the F/A-18 Hornet, after clocking up over 1,000 hours on the Phantom, including a six-month course to become a Phantom Qualified Weapons Instructor.

One of the first things Anderson noticed about the Hornet was the much-improved ergonomics of the cockpit. An example he gave was the location of the IFF transponder control box. On the Phantom, it was to the rear of the left-hand side panel so, to adjust the settings on it, you had to look down and twist your head at the same time. This movement can cause a 'Coriolis Trap' in the body's balance system which, after turning your head simultaneously in two directions, could give you a disorientating spinning sensation. Regrettably, this has, on occasions, resulted in loss of aircraft and crew.

The cockpit was very modern with a Head-Up Display (HUD), two CRT screens and several multifunction control boxes. There was a moving map display which was a film projection rather than a digital system. The primary flying display information was projected on the HUD, although it could be shown on either CRTs, as could Nav data and engine parameters.

The Hornet is a fly-by-wire aircraft. Therefore, the pilot has no idea of what the flight surfaces

are actually doing. Like a modern airliner, the pilot, the stick and rudder pedals tell the Flight Control Computers (FCCs) what he/she wants to achieve and the FCCs move the controls appropriately.

Before Anderson could start his conversion course, he had to be vetted and approved by the US Navy as it was the sponsor for the RAAF aircraft. While that was being processed, Anderson managed to get some basic flying training done. During one simulator session, the instructor told him to fly down the runway at 1,000ft and roll inverted. Anderson duly complied and as he went inverted, the instructor froze the sim and told him to leave the 'aircraft.' This was harder than it seemed as the sim graphics were so good, it felt like going 1,000ft off the ground.

Later parts of the course took place at RAAF Townsville, Queensland where low-level navigation exercises occurred. Once you had fought your way through 'enemy' aircraft on the exercise, you dropped live ordnance 500lb GP bombs on Cordelia Island. Once Anderson completed the course, he joined 77 Sqn.

During his time with the RAAF, there was a deployment to the Philippines and Anderson was tasked with flying the spare aircraft up to Darwin. After the detachment arrived in Darwin without any mishaps, Anderson was to bring the aircraft back to Williamstown. As he was a 'tourist', Anderson's boss suggested that he may like to return the long way round – Alice Springs, Perth, Edinburgh and back home to Williamstown.

▼ Flt Lt Nick Anderson in his F/A-18 Hornet at RAAF Williamstown, Newcastle, New South Wales.

Nick Anderson



As the deployed aircraft headed north towards the Philippines, Anderson headed south with Uluru (also known as Ayers Rock) programmed into his targeting computer. After a few circuits of Uluru and fuel getting low, he headed for Alice Springs. On his targeting computer, a red circle appeared not far off his track. Due to INS drift, instead of flying abeam, it flew directly over this group of buildings. After landing at Alice Springs, Anderson was met by several 'men in black.' It turned out that this red circle was a place called Pine Gap, a highly secret joint Australian/US satellite surveillance station run by the CIA. The men had taken exception to it being overflown and the fact Anderson had a camera with him. However, he was able to calm their fears and explain the situation.

During Anderson's time down under, the squadron was deployed to New Zealand to carry out an exercise with 74 Sqn NZAF, flying A-4 Skyhawks. He was very impressed with the NZ pilots' abilities with the Skyhawk being permitted to fly as low as 100ft.

Every year there was a six-week exercise in Malaysia where the Hornets would take on

the Malaysian AF F-5 Tiger IIs. It was here that Anderson had an introduction to what would be his next steed when he returned to the UK – the Air Defence Variant of the Tornado, the F.3. At the time, British Aerospace was on a sales tour of the region with the F3 and the Hawk. Despite badgering from the Air Force team, BAe was reluctant to take on the Hornet with the Tornado in anything other than in well-rehearsed scenarios. Eventually, one of the new Hornet pilots got the Tornado to turn with him and the result was that guns 'kill' for the Hornet, the general opinion of the aircraft being that 'it was a bit of a dog.'

It was shortly after this period that his deployment came to an end and he returned to the UK as a Tornado F.3 flight commander with 111 Sqn, in which he found the rumours about the Tornado F.3 to be true.

We hope to hear about Nick Anderson's final Air Force tour and the F.3 during a talk in our 2024/25 lecture season.

Paul Robinson
MRAeS



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or email CPD@aerosociety.com



GROUNDBREAKING RAeS AAM SAFETY PAPER



Andy Hay – Flying Art/RAeS

Brought together by outgoing RAeS President 2023-24, Kerissa Khan, a group of global experts have contributed to an innovative 'future gazing' RAeS discussion paper, called *Shaping the future of Advanced Air Mobility Safety*, discussing the challenges facing the emerging Advanced Air Mobility sector – and in particular – the emerging class of passenger-carrying eVTOLs.

Taking the form of three plausible, yet fictional air accident investigation scenarios from the near future, this paper seeks to inform and educate stakeholders on the challenges ahead in integrating these air vehicles into the current aviation system while maintaining the highest level of safety standards, and offers recommendations to industry from this multidisciplinary group drawn from a series of workshops over several months.

The three fictional vignettes, set in London, Asia and the Americas highlight the novel ways in which eVTOL vehicles and operations may present new safety considerations – whether in design, MRO, airspace/ATM or human factors, in an innovative, 'pre mortem' approach that is highly readable, yet provides expert and thought-provoking recommendations for this nascent aviation sector.

► To download your PDF of *Shaping the future Advanced Air Mobility Safety*, scan the QR code.



ATM GROUP RELEASES NEW PAPERS

The RAeS' Air Traffic Management Specialist Group recently released three new papers to highlight the concerns facing the UK aerospace industry regarding rising air traffic levels in the post-Covid era. To download the PDF's, see here:

<https://www.aerosociety.com/news-expertise/policy-public-affairs/briefing-papers-and-reports/>



Air Traffic Control Staffing



GNSS services supporting the UK



ATM/ASM Contribution to Net Zero and Climate Change Issues'

Obituary

GRAEME GILMORE



FRAeS
1938-2023

Air Commodore Graeme Bernard Gilmore OBE FRAeS RNZAF (Rtd), who was a highly respected aeronautical engineer and pilot, died on 9 December 2023 aged 85.

Graeme served in the Royal New Zealand Air Force from 29 August 1956 to 30 June 1989 as an Engineering Officer. He began his training at Royal Air Force Station Henlow in Bedfordshire, England. Although an engineer by trade, he completed training as a pilot and 'earned his wings' in 1961. During his time in the RNZAF, he served in the United States and Australia. In 1972, he was posted to Washington to serve as the Senior Technical Officer to the Defence Liaison Staff, a post he held for just under four years before returning to New Zealand in 1976. In 1981, Gilmore was awarded his OBE for services to the New Zealand Defence Force.

Graeme spent 33 years in the RNZAF, retiring as an Assistant Chief of Defence Staff. His subsequent civil career included roles as General Manager of Safe Air, Engineering Operations Manager at Air New Zealand and Vice President Engineering at China Airlines in Taiwan – all of which he discharged with distinction.

One of Graeme's many achievements included the management of the Production Phase of the RNZAF C-130 Hercules Life Extension Programme (LEP) at RNZAF Base Woodbourne. The chosen course to complete the last three aircraft was to

set up a new organisation from scratch in what was then a complex political, commercial, technical and regulatory environment. The C-130 LEP proved to be an immense challenge, being the largest modification and repair programme ever undertaken on any aircraft type in New Zealand and the most extensive C-130 programme anywhere in the world. Up to 200,000 man-hours of specialist work was required on each aircraft. Graeme put together and provided the leadership for a highly skilled team that managed a myriad of sub-contractor, contractor and agency relationships.

Graeme strongly supported the RAeS as a member for 63 years. He was also President of the New Zealand Division from 1983 to 1985. In 2014 he was awarded the Meritorious Service Award for services to military and commercial aviation, specifically with the C-130 programme.

Graeme's achievements over his lifetime were substantial and are hugely admired and appreciated within the New Zealand aviation sector. He was a wise, extremely capable and competent Commander and Senior Manager, who led by example and provided career guidance and mentoring to a significant number of prominent aeronautical and maintenance engineers. Graeme was a highly respected aviator who leaves a legacy of excellence.

Mike Lynskey
MRAeS

NEW RAeS AUSTRALIAN PRESIDENT-ELECT NAMED

Margaret Staib has been selected as the President-Elect of the RAeS Australian Division. Margaret is a former Senior Officer in the RAAF where her military service included holding the position of Commander Joint Logistics and Commandant of the Australian Defence Force Academy.

From the Air Force, Margaret continued her executive career as the CEO and Managing Director of Air Services Australia from 2012 to 2015. Margaret has subsequently pursued a career as a Non-Executive Director with Sydney Airport, QINETIQ Australia, Vault Cloud, Chair of the Australian Logistics Council and Councillor with the RAeS Australian Division.

A long-time advocate and supporter of aviation in Australia, Margaret brings with her a passion and drive that will take the Society into the future.

We would also like to take this opportunity to acknowledge and thank our Past President, Geoff Wilkinson for his support over the past two years. Geoff will remain on Council and continue to provide guidance and direction for ICAS 2026.

CONGRATULATIONS



Margaret Staib
President-Elect

Royal Aeronautical Society
Australian Division



THURAIRAJASINGAM RAHULAN



FRAeS
1958-2024

Life's journey has an end, and one beautiful soul, Dr Thurai Rajasingam Rahulan, affectionately known to all of us as Thurai, completed his journey on 22 February 2024. A journey of a remarkable man who along the way touched the lives of many individuals, including me. Thurai's life started in what was Ceylon, now Sri Lanka, in 1958 and eventually came to the UK where he studied Mechanical Engineering at the University of Salford, graduating in 1979. His research in the field of control theory in multimode systems earned him his doctorate in 1984 and soon after he commenced full-time employment on a Ministry of Defence project. In 1988, he moved to Jaguar Cars Ltd, Coventry and eventually moved back to Salford University in 1990 to teach aeronautics. It was in 1985 when I first met Thurai. He had come for an interview at Loughborough University for a lecturer's job which he declined. We struck a chord and I had been in touch with him ever since. It was on Thurai's insistence that I applied for Fellowship at the RAeS in 2022 and he was one of my supporters.

Thurai's calm and reassuring demeanour left an impression on all who engaged with him. He made invaluable contributions in the field of engineering and achieved significant professional recognition. He served on the Council of the RAeS and was the Chair of the RAeS Manchester Branch, Chair of the Association of Aerospace Universities between 2006 and 2022, Executive Board member of the Engineering Professors' Council, Chair of the EPC's Aerospace Sectoral Group for more than eight years, External Examiner at Al Ghurair University in

Dubai, among many other roles. He was one of the editors of a book called *Multiphysics Simulations in Automotive and Aerospace Applications*. It is worth acknowledging his commitment to the John Barnes student conference, the Go-Fly competition and others that served to inspire and enthuse students.

While I was at the University of Hertfordshire, he was our External Examiner and acted as an external panel member for the periodic review of the university's engineering provision, during which time I got to know him even better. He was humble to the core, a reservoir of knowledge and wisdom and his amused smile was priceless. He invited me to give a lecture at the Manchester RAeS Branch in 2018 where I met with his students and the Branch membership. Students had nothing but glowing praise for his knowledge, inspirational qualities, wit, grace and professionalism. Every student that I spoke with said one thing: 'he was a brilliant teacher and mentor.' The ones who know do and the ones who understand teach, and that is exactly what he did, and brilliantly as well. We have lost a beacon of knowledge. The memories of the association with him will linger on and he will be remembered fondly, and his presence will be sadly missed. When I was young, I asked my grandfather what happens to people when they leave us and he said: "they become the stars in the sky." I cannot help but gaze at the night sky and say: Thurai, you are the brightest star in the night sky.

Rashid Ali
PhD CEng CITP FBCS FRAeS

BRANCHES CONFERENCE

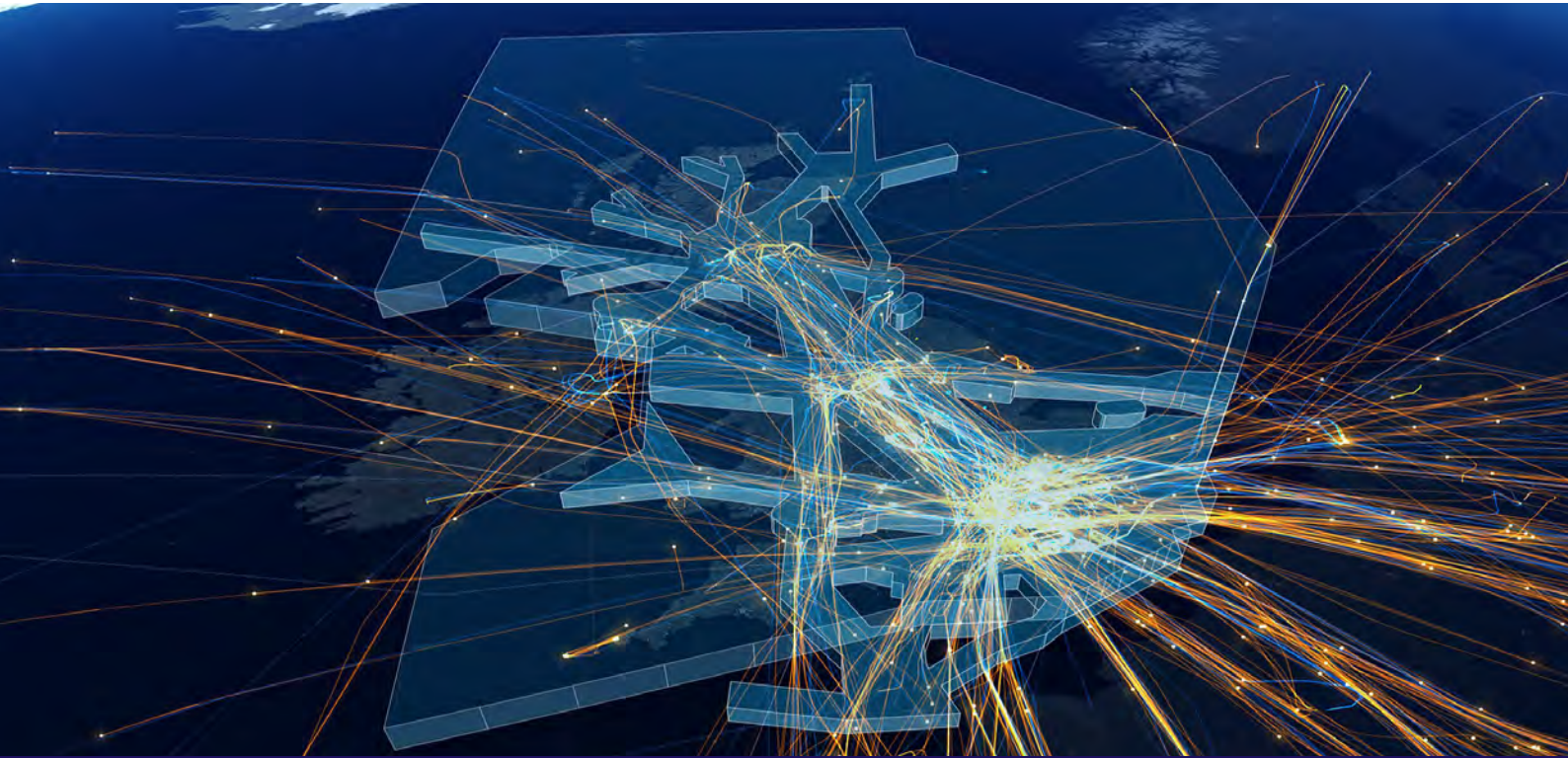
Members of both UK and overseas Branches are invited to make a late booking to join around 45 delegates by attending the 113th Branches Conference, to be held on **14 and 15 June 2024** at the Cambridge Belfry Hotel and Spa. The theme of the conference will be 'Sustaining the Branch Network' and will build on the outputs from the Branches Conferences in 2022 and 2023. There will be participative workshops and presentations from one external and several internal speakers, together with plenty of time for networking. You do not have to have attended the 2022 or 2023 conferences to be able to gain something for your Branch. Furthermore, there will be a Partners' programme on the Saturday.

The Conference will commence with registration at 2:30pm on Friday, 14 June, with a gala dinner that evening, and will finish at about 4:00pm on Saturday, 15 June. If you are interested in attending, please contact the hosting Branch at **Cambridge@aerosociety.com**.

UNIVERSITY OF BRISTOL
11-13 JUNE 2024



CEAS EUROGNC CONFERENCE 2024



Booking is open for the CEAS Conference on Guidance, Navigation and Control (EuroGNC), taking place on 11-13 June 2024 in Bristol.

EuroGNC is an applied conference with a strong aeronautics and space orientation. Non-aerospace applications with similar challenges and modelling approaches will be discussed (including examples from sectors, such as automotive, robotics, wind energy and underwater vehicles), as well as theoretical works that are applicable to the aeronautics and space problems within the scope of EuroGNC.

Join us for three days of technical discussions and networking, with the unique opportunity to join the conference dinner taking place at Aerospace Bristol right under the wings of Concorde!

Book your place via our website by scanning the QR code or visiting www.aerosociety.com/eurognc2024



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Library Additions

BOOKS

SERVICE AVIATION

Co-operation of aircraft with artillery by the War Office, Revised edition, Dec 1917, 80pp.

Pamphlet

The Royal Air Force by Stanhope T. Sprigg, Revised edition, 1941, Collins, 72pp.

AIRCRAFT MODELS

Model Gliders: How to make and fly them by E. W. Twining, [1908], Percival Marshall & Co Ltd, 13pp.

AIR MINISTRY HISTORICAL PAMPHLETS FROM THE LETTICE CURTIS COLLECTION

Manual of air navigation by Air Ministry, 1933, 359pp.

Orfordness rotating wireless beacon: instructions for taking bearings by Air Ministry, 1929, 8pp.

Meteorology for aviators by R.C. Sutcliffe, Air Ministry, 1940, 274pp.

LAW AND REGULATIONS

The Regulation of Air Transport: From protection to liberalisation, and back again by Barry Humphreys, 2023, Routledge, 258pp.

The regulation of modern civil aviation has its roots in the later years of WW2. An intense debate regarding the future regulatory framework led to a compromise that continues to shape the global airline industry today. However, progress towards further normalisation of the industry seems to be slowing down.

ROYAL AIRCRAFT ESTABLISHMENT TECHNICAL REPORTS COLLECTION

Hygrothermal effects in CFC laminates: Part 1, strains induced by temperature and moisture

by D.E.W. Stone, Oct 1983, Problems in the use of ultrasonic attenuation measurements for the determination of void content in CFRP by D.E.W. Stone, Jul 1976.

Problems in the nondestructive testing of carbon fibre reinforced plastics by D.E.W. Stone, Sep 1974

FOREIGN LANGUAGE TITLES

Les Moteurs Gnome: description conduite entretien by Lieutenant Remy, [1911], Librairie Aéronautique, 41pp.

Note retrospective documentaire d'aerotechnica: primo supplemento alla "Biblioteca Aeronautica Italiana" by Giuseppe P Boffito, 1930, 25pp.

Intorno alla direzione degli aerostati: seconda lettera al Prof. Giuseppe Gazzeri by Napoléon-Louis Bonaparte, 1828, 5pp.

National Aerospace Library Book Sale

Friday, 14 June 2024 - 10:30am-2pm

National Aerospace Library, The Hub, Fowler Avenue, Farnborough Business Park, Farnborough, Hants GU14 7JP, UK

Saturday, 15 June 2024 - 11am-5pm

Blackbushe Air Day, Blackbushe Airport, Hampshire, GU17 9LQ

100s of donated aviation books and 1,000s of magazines will be for sale. All proceeds to conserve historic aviation material in the Library's archives.

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Diary

EVENTS

1 May

Boeing Cascade: Advancing a more sustainable aerospace, together

Brian Moran, Chief Sustainability Officer, The Boeing Company
Royal Aeronautical Society, No.4 Hamilton Place, London W1J 7BQ

8 May

Hatfield Branch: Annual General Meeting

Steve Rogers, Hatfield Branch Chair
De Havilland Aircraft Museum, Salisbury Hall, London Colney, St Albans, Hertfordshire AL2 1BU

8 May

Brough Branch: Life as a Weapons & Explosives Engineer – 'An Armourer's Tale'

Arthur Akrill M.I.Exp.E. Hawk Weapons & Explosives Engineering
BAE Systems
BAE Systems, Brough, Saltgrounds Road HU15 1EQ

9 May

RAeS Annual General Meeting
Royal Aeronautical Society, No.4 Hamilton Place, London W1J 7BQ

14 May

Farnborough Branch: The Royal International Air Tattoo - from small beginnings

Tim Prince OBE FRAeS
Farnborough College of Technology, Boundary Road, Farnborough GU14 6SB



▲ Click on the QR code to learn more about the FCAS Summit taking place at the RAeS HQ on 21-23 May.

15 May

Medway Branch: Subject to be announced

Guy Bartlett
BAE Systems, Airport Works, Marconi Way, Rochester, Kent ME1 2XX

16 May

Birmingham, Wolverhampton and Cosford Branch: Historical Development of the Coaxial Contra-Rotating Propeller

Antonio Filippone PhD, FRAeS, FIMechE, CEng
RAF Museum Cosford Lecture Theatre, RAF Museum Cosford, Shifnal TF11 8UP

16 May

RAeS Annual Banquet 2024

InterContinental London Park Lane Hotel, 19:00 to 23:00

16 May

Isle of Wight Branch: 8th Sam Saunders Lecture - FRESSON Hydrogen Fuel Cell B-N Islander Project

Rob Marsh CEng FIMechE FRAeS - Director of Engineering and Chief Engineer FRESSON - Cranfield Aerospace Solutions Ltd.
Isle of Wight College, Main Hall, Medina Way, Newport PO30 5TA

17 May

RAeS Lecture: Sopwith to Spitfire - A revival of heritage propeller production

Rupert Wasey - Founder and Owner of Hercules Propellers
Royal Aeronautical Society, No.4 Hamilton Place, London W1J 7BQ

21-23 May

RAeS Future Combat Air and Space Capabilities Summit 2024

Royal Aeronautical Society, No.4 Hamilton Place, London W1J 7BQ

For further information and booking, visit aerosociety.com/events-calendar/

Book Reviews

BRITAIN AND THE POLITICAL ECONOMY

of European Military Aerospace Collaboration, 1960-2023

by Prof Keith Hayward

Cambridge University Press, 2023, 70pp, £17 paperback & e-book.

In the world of military aviation, the journey from the drawing board to the front line is often fraught with political and economic battles. Keith Hayward's book provides a guide to this journey, focusing on the projects that have shaped Britain's military aircraft industry.

Hayward's analysis extends back to his undergraduate days in the late 1960s when Britain was cancelling its military aircraft projects in favour of American purchases and European collaborations. It highlights how political leaders often find themselves in the cockpit, figuratively and sometimes literally, influencing the fate of various aircraft projects from their earliest stages. The narrative is enriched with tales of cancelled projects, like the infamous BAC TSR-2 bomber, and successful ones, like Tornado.

Unable to escape the politics that shapes projects, the book shows how the industry has adapted to its influence. The evolution of collaboration, with bitter experience informing the next iteration, reveals how some of the failures led to successful aircraft, like the Jaguar, Tornado and Typhoon. Britain's commitment to collaboration is contrasted with France's often techno-nationalist approach to military aviation projects. France's involvement, and withdrawal, from what became the Eurofighter Typhoon serves as a prime example of how politics can shape and scar a project. To keep France in, the weight was kept down – Britain wanted a heavier



The evolution of collaboration, with bitter experience informing the next iteration, reveals how some of the failures led to successful aircraft, like the Jaguar, Tornado and Typhoon

aircraft at the outset but stuck with the joint design. It is notable that today, France has not been invited to take part in the Tempest project, while Italy, part of the Tornado and Typhoon team, has. Hayward also shows how the technical and political difficulties have been mediated by the organisations that developed these projects. Joint ventures, like Eurofighter and Panavia, helped navigate conflicting national demands but took time to establish. However, unlike in the civilian domain, where Airbus eventually became a proper company that now includes much of the European military aircraft sector, many of the organisations that have developed military aircraft are stand-alone entities. Britain has stuck with these ad hoc collaborative arrangements, partly to allow room to work with the US, like the Joint Strike Fighter (JSF) project. It is here that the reader might want to learn a little more about the reasons and effects of such an approach. Is it better to keep options open or to commit fully? The JSF experience is something that Britain does not seem to want to repeat with the emerging Global Combat Air Programme (see Fighting for the the market, p16). The book shows that tailored arrangements can work, but more details would help the reader to know how.

There are a few small errors, such as the attribution of TSR-2 to both the British Aircraft Corporation and Hawker Siddeley, that are presumably ones of editing rather than the author's considerable knowledge. Apart from that, this is a useful and timely survey of more than half a century of change and challenge. This short book is a must-read for anyone interested in understanding the complex interplay between politics, economics and technology in military aviation, and serves as an excellent introduction to the subject.

Michael Pryce
MRAeS

NEW AIR TRANSPORT SPECIALIST GROUP CHAIR

Jim Angus recently stood down as the Air Transport Specialist Group Chair and, having been an inspiration to us all over the years, we wanted to mark this moment to be memorable for him. We were very pleased to come together on 7 March 2024 to present to him a gift and embarrass him with speeches. It was touch and go as to if he were teetotal, but latest dispatches were that the hip-flask was in the Kielder Forest, filled with a fine malt whisky, though probably empty now.

► (L-R) Neil Gunnell, Secretary FOG, Sohail Chughtai, Chair ATSG, elected December 2023, Jim Angus, Chair ATSG 2010-2023, Alison Wilds, Secretary ATSG, Peter Forbes, Member ATSG. Sohail Chughtai



PARIS RAES BRANCH CELEBRATES 20 YEARS

On 2 April, the RAeS Paris Branch held a dinner in celebration of the first 20 years since its creation, which took place in the restaurant of the Aero Club of France in Paris.

We were honoured that RAeS President 2023-24, Kerissa Khan was able to attend and to give a speech, followed by a speech given by David Cook, the Branch President, and a word of thanks from myself at the end.

Howard Nye

Vice President, RAeS Paris Branch
Chair, RAeS Space Specialist Group

► Paris Branch members joined Branch President, David Cook, VP, Howard Nye and RAeS President 2023-24, Kerissa Khan at the celebratory dinner.

Howard Nye

◄ Click on the QR code to read the full speech read by David Cook, RAeS Paris Branch President, at the 20-year anniversary celebration.



THE RAeS FUTURES SCHOLARSHIP AWARDS IS NOW OPEN FOR APPLICATIONS

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Dilani Selvanathan - Futures Individual Awardee 2023 - (International Space University Programme)



"I am so excited by the skills I will develop, and the career. Thank you once again everyone at the RAeS"

Tilly Watts - Futures Individual Awardee 2023 - (Instrument Rating Recipient)



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Applications close on Friday 7th June at 5pm

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New Member Spotlight

NEW MEMBER SPOTLIGHT

Name: Jessica Chatburn

Grade: AMRAeS

Location: Bristol

Job title: Wing Structures Design Engineer

What inspired you into aviation/space/aerospace? We have a family full of engineers, including my great grandad who was an engineer and my great uncle who is a retired aerospace design engineer and loves to encourage and support me in my chosen career. At school, I had a female science teacher who encouraged me to enter STEM challenges, and particularly the International Science Photographer of the Year competition, which I won. This made me realise how science could link with my interest in art and design and helped encourage me to look into design roles within the engineering sector. It's a realisation that science and creativity can be interlinked, rather than something that you study separately.

What is the best thing about your current role? I love using the CAD software to create or update models and drawings and, when I am not doing CAD modelling, I am liaising with suppliers and leading projects. There are opportunities to travel which allows me to see the other sites of the company, as well as supplier visits to see the product we design and the final assembly of the aircraft. Visiting and seeing the product in person is such a great feeling, as it helps me connect all the pieces of what we do. Comparing the actual product to the visualisations on the computer allows me to have a better understanding of the design and how all the components link with each other.

What career path did you take to get to where you are? I joined Airbus in 2018 after completing my A Levels (Maths, Physics and Fine Art) as an aerospace undergraduate apprentice, which allowed me to study and work at the same time. I attended the University of the West of



England and studied an Aerospace Engineering degree, attaining a first-class qualification. I completed the apprenticeship at the end of 2022 and started full-time as a Design Engineer in January 2023.

What made you join the Royal Aeronautical Society? I joined the Society as I am passionate about aviation, it keeps me up to date with industry news, enables networking opportunities and, hopefully, will support me to become a Chartered Engineer in the future.

What do you hope to get out of your membership with the RAeS? The end goal is to achieve chartered status but, my first goal is to achieve IEng which I hope to apply for soon. I also like reading the different articles in the newsletters and seeing inspirational stories or events which are taking place that I want to attend. Seeing people do well and achieve their goals always helps me put things into perspective and makes me realise that I can do anything I set my mind to.

What three items would you take with you to the Space Station? I would take my sketchbook, as I love to draw portraits and sketch random doodles. The second item would be a picture of my family to remind me of them. The third item would be my necklace to remind me of home. It used to be my mum's, but she gave it to me when I left home and moved to Bristol to start my apprenticeship.

Who is your biggest inspiration? Mandy Hickson, a former fighter pilot. She was the only female pilot on her front-line Tornado squadron, flying multimillion-pound fast jets for the Royal Air Force. My grandad bought me her book *An Officer, not a Gentleman*.

Piece of advice for someone looking to enter your field? Just be yourself, you are enough.

Elections

FELLOWS

Saleh AlGhamdi
Sean Ashton
James Barker
Robert Bishton
Andrea Cammarano
Jen-Yuan (James) Chang
Kimberly Coryat
Gordon Dickman
Matthew Emery
Thea Feyereisen
Jason Gill
Matt Goodwin
Johannes Hien
Chris Keane
Sara Kreil
Tim McCarthy
Richard Millerin
Zuhair Mir
Runwei Mo
Amanda Owen
Silvestre Pinho
Ravinder Rathore
Tom Reynolds
Steven Roy
Mark Rubin
Annalisa Russell-Smith
David Sullivan
N Swaminathan
Douglas Thomson
Rehan Umer
Johan Visser
Simon Whalley
Fraser Wilson
Andrew Wood
Gurjit Wood

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Jordan Lowrey
Ian McDermott
Jordan Mitchell
Haris Mohamed
Sean Mooney
Howard Morris
Chris Moxon
Gokul Ganesh Murali
Mohd Izzed Mustaffa
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Ramin Norouzi
Adam Parker
Thomas Paul
Ana Belen Postigo Castro
Alessandro Ramazzotti
Duncan Read
Brice Reding
Edward Reis
Afolabi Rotibi
Alexander Schuett
Edwar Seymour-Smith
Scott Shevels
Viswanath Siddhanthi
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Harry Llamas
Pratheesh Muruganantharajah
Joshua Nandy
Ollie Reynolds

WITH REGRET

The Royal Aeronautical Society announces, with regret, the death of the following members:

Brian John Allinson MRAeS 79
David Antrobus MRAeS 83
Norman Arthur Barfield FRAeS CEng 92
Peter Charles Brooks FRAeS CEng 88
Norman Stanley Currey FRAeS CEng 97
Noel Falconer FRAeS 90
Steven Peter Jones 65
Christopher James Lampard AMRAeS IEng

Haroon Shahzad
Rosie Sinden

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Poppy Howe
Rehaan Hussain Jageer Hussain
Taylor Jamieson
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Phil Hornsey
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Ronald Eras Xavier
Bautista

Major Ahmad Fauzi Bin Puad
Manith Lakvindu Sumanasekara
Biyawila Kankanamalage
Jett Boshars
Sai Nischal Reddy
Boyapalle
Allan Byrne
Bethany Doyle
Sam Eghtedari
Ken Ely
Spruha Itankar
Devansh Kakkar
Vincent Kannan
Amandeep Kaur
Collins Kibamut
Toby Milroy
Mohammad Naquiuddin
Mohammad Nazri
Aditya Neurgaonkar
Timothy Ramsay
Theodore Strobel
Calvin Tan
Baochen Xu

The Last Word

COMMENTARY FROM

Professor Keith Hayward
FRAeS



Are we in a new arms race?

The term 'merchants of death' was originally applied to the companies and individuals who had supplied the combatants during WW1 but was picked up and used during the US Senate hearings, held by Senator Nye in the 1930s.

No evidence of a conspiracy to trigger war was revealed and Nye overreached himself by accusing President Wilson of deliberately taking the US into war in 1917.

In the UK, Prime Minister Stanley Baldwin described the 'hard faced men who have profited from the war' who filled his backbenches in the 1920s.

Arms makers and provisioners have, undoubtedly, made money from wars and warfare throughout the ages but to assign blame to armaments firms for war itself is something of a stretch. To cite an academic cliché, 'war is a multicausal phenomenon' and it is certainly hard to demonstrate how far arms races lead to war.

Arms racing

Back in the 1920s, the British statistician, Lewis Richardson, tried to reduce arms racing to a set of differential equations but, while theoretically interesting, empirical proof was hard to come by.

Modern arms racing theory has also proven to be less than convincing. One classic model was the 'action-reaction' relationship apparently exhibited by the US and USSR in developing nuclear weapons – one side would trigger the other into a spiral of mutual and perhaps destabilising arms development and deployment. Again, more detailed studies of how, why and when some of the supposed key triggers were made revealed a far more complicated and often independent set of decisions.

So why cover some old and musty academic and rhetorical issues? Well, the current outburst of warfare and threat of escalation, combined with what looks like a 'classic' arms race involving China and the US, has generated in my mind a strong sense of déjà vu.

Good for some

On the one hand, global spending on arms has surged by over 10% in the last two to three years. The 15 largest defence companies have combined orders for \$777.6bn. Profits have followed and US and European governments have been warned of the need for an old-style industrial mobilisation to support Ukraine and other allies facing hostile neighbours. Some of this is redolent of the 1916 munitions crisis that brought down the Asquith government, delivering 'dumb' shells in larger numbers than Russia and its suppliers can. Military expenditure in Europe had its steepest year-on-year increase in at least 30 years as governments in the region announced new orders for ammunition and tanks to replenish national stockpiles depleted by donations sent to Ukraine. Gearing up the production of more complex guided weapons and platforms – a far more challenging requirement – is also under way. In this respect, there are no 'shadow factories,' as created by the UK in the 1930s, which would form the basis for a massive wartime aircraft building programme.

Arms races don't help to ease tension

I used to make the rather flippant remark about the US-USSR arms race that what armament firms really appreciated was not war itself, which might damage their infrastructure, but a persistent and consistent era of sustained tension. This would bring the steady public investment in research and successive generation of kit that might not be used. The Vietnam War was an aberration, an exception that proved a loose rule.

The rising tensions in the Far East have echoes of the Dreadnought arms race between the UK and Germany that Richardson modelled in the 1920s. However, while the naval arms race clearly exacerbated hostilities between Britain and Germany, it did not cause the Great War. There is the rub – filling the Pacific with carrier task forces and long-range missiles – not to mention the odd rogue nuclear power – will not help to cool matters down.

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